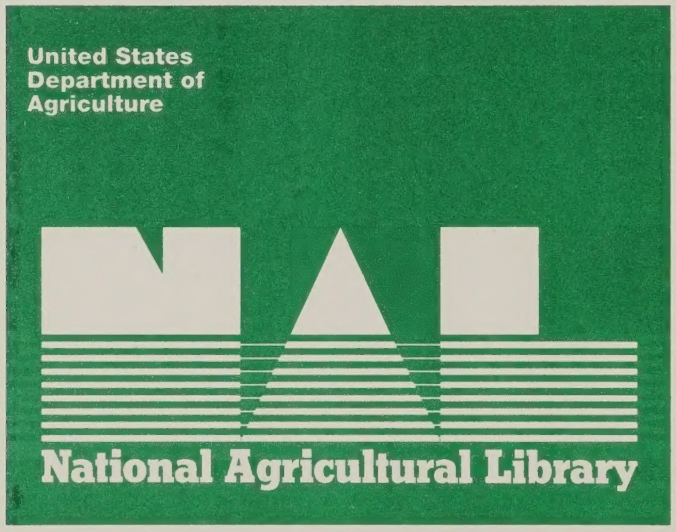
June 1998

# Silverleaf Whitefly

## National Research, Action, and Technology Transfer Plan, 1997–2001: First Annual Review of the Second 5-Year Plan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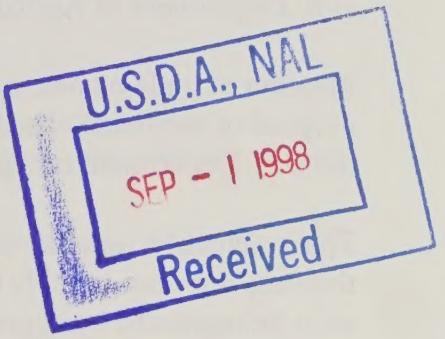
## National Research, Action, and Technology Transfer Plan, 1997–2001

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(Formerly Sweetpotato Whitefly, Strain B)
First Annual Review of the Second 5-Year Plan
Held in Charleston, South Carolina,
February 3-5, 1998

In cooperation with USDA/Agricultural Research Service, USDA/Cooperative State Research, Education, and Extension Service, State Agricultural Experiment Stations, USDA/Animal and Plant Health Inspection Service, and USDA/Extension Service.

Henneberry, T.J., N.C. Toscano, T.M. Perring, and R.M. Faust, eds. 1998. Silverleaf Whitefly: National Research, Action, and Technology Transfer Plan, 1997–2001 (Formerly Sweetpotato Whitefly, Strain B): First Annual Review of the Second 5–Year Plan Held in Charleston, South Carolina, February 3–5, 1998. U.S. Department of Agriculture, 1998–01, 187 pp.



While supplies last, single copies of this publication may be obtained at no cost from Robert M. Faust, U.S. Department of Agriculture, Agricultural Research Service, BARC-West, Bldg. 005, Room 338, Beltsville, MD 20705.

Copies of this publication may be purchased from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161; telephone (703) 605–6000.



Issued June 1998

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## Editors' Comments

Henneberry, T. J., N. C. Toscano, T. M. Perring, and R. M. Faust (eds.) 1998 Silverleaf Whitefly Supplement to the 5-Year National Research, Action, and Technology Transfer Plan (1997-2001). Charleston, SC, February 3-5, 1998.

This document describes mechanisms for current and future technology transfer and outlines silverleaf whitefly research priority goals for the years 1997-2001. The plan encompasses studies on: (A) biology, ecology, and population dynamics; (B) viruses, epidemiology, and virus-vector interactions, (C) chemical control, biopesticides, resistance management, and application methods; (D) natural enemy ecology and biological control; (E) host plant resistance, physiological disorders, and host-plant interactions; and (F) integrated and areawide pest management approaches, and crop management systems. It also facilitates a coordinated technology transfer process and community-based partnership for implementation of areawide silverleaf whitefly IPM programs. The editors sincerely thank all those who participated in the development of the new research and technology transfer plan.

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**Acknowledgments:**
The USDA Silverleaf Whitefly, Research, Education and Implementation Coordinating Group; Annual Review Program Chairs; Local and State Coordinators; SLWF Program Planning and Review Committee; and the Silverleaf Whitefly Working Group sincerely appreciate the contributions of all the participants and those who have helped in organizing the 1998 meeting.

## Preface

The Silverleaf Whitefly (SLWF), *Bemisia argentifolii* Bellows and Perring, National Research, Action, and Technology Transfer Plan (1997-2002) is an extension of the "5-Year National Research and Action Plan for Development of Management and Control Methodology for the Silverleaf Whitefly (formerly, sweetpotato whitefly, Strain B)" that was initiated in 1992. The duration of the new research, action, and technology transfer plan is also expected to be 5 years. The silverleaf whitefly remains a serious national and international pest problem, resulting in estimated crop losses exceeding $500 million a year in the United States. The new plan defines the continuing need for a highly coordinated and cooperative program that includes the participation of federal and state agencies, universities, and the agricultural industry. It also establishes new research needs, goals and objectives, and provides for technology transfer to clientele (scientific community, legislators, regulators, the agricultural industry, and the public).

Progress in reaching goals and objectives will be reviewed on an annual basis. The new plan retains flexibility that will allow responsiveness to changing needs and priorities. As the SLWF program continues to progress, participants will redefine essential activities and make appropriate adjustments to terminate, redirect, or add priorities based on funding, current knowledge, and program needs. The primary purpose of the plan is to provide focus for developing essential research and team efforts that will produce environmentally and socially acceptable, efficient and adoptable technologies for potential areawide, community-based silverleaf whitefly management.

This plan has been developed through the cooperative efforts of USDA agencies (ARS, APHIS, and CSREES), state agencies, state agricultural experimental stations, and the cotton, vegetable, ornamental, nursery crop and chemical industries. Our goals are to stress team research, address the highest priority research areas, avoid duplication of effort, and maximize the use of existing resources.

Important administrative responsibilities for the overall activity reside with the USDA Silverleaf Whitefly Research, Education, and Implementation Coordinating Group, and the Silverleaf Whitefly Working Group. The USDA Coordinating Group provides for coordination of USDA interagency activities and partner state agricultural experiment stations, and helps ensure a unified effort in support of the plan by assisting in annual progress reviews, identifying research and action priorities, and implementing technology transfer strategies. The Silverleaf Whitefly Working Group (previously Silverleaf Whitefly Technical Committee), composed of members from federal and state agencies, industry, universities, commodity groups, and other appropriate interest groups, meets annually and provides an information link to the USDA Coordinating Group. It also provides input to the Silverleaf Whitefly Program Planning and Review Committee, which schedules progress reviews, selects review locations, prepares reports, and helps guide the priority setting process.

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## Executive Summary

From 1992 to 1996, the *Bemisia tabaci* strain B (= silverleaf whitefly) 5-year national research and action plan was a focal point for coordination; facilitation of cooperative research; and development of linkages among federal and state agencies, state agricultural experiment stations and commodity industries. A new research and technology transfer plan, adopted in San Diego at the fifth annual review of the terminated plan, provides for continued research, methods development, education, extension, and technology transfer. The new plan is expected to achieve the same or higher level of success as the original plan, with expanded participation from foreign countries as well as the United States. A proactive mechanism for technology transfer has been developed. Priority research and action areas have been revised to reflect our current knowledge of the silverleaf whitefly problem, provide for technology transfer to our clientele, and develop areawide or community action programs. Annual reviews have been effective for information exchange, analyses, and identification of research needs, and will continue to be a vital part of the new plan.

A complete management system for silverleaf whitefly is a goal for the future, but at present, it is in the formative stages. Extensive fundamental, ecological, and biological research on the silverleaf whitefly and its natural enemies has revealed potential components for

incorporation into an ecologically-based management system. Some crop management and community-oriented farm practices, such as water-use patterns, proximity of alternate host crops, and spatial considerations, are being implemented in an effort to provide overall silverleaf whitefly population reduction. Knowledge of the complex host interrelationships among cultivated crops, crop growing sequences, and urban community hosts has focused awareness that the farm community must concern itself with silverleaf whitefly population suppression programs. The new research and technology transfer plan identifies further research and action activities to develop effective management methods and to increase our levels of technology transfer. Areawide, community-based approaches covering all commodities have emerged as having the best possible chance of success. Farmers must give careful consideration to all crops in the area, planting sequences, growth, and proximity to other crops. Crop production inputs also are important factors in silverleaf whitefly management for the numerous crops it attacks. The mechanisms involved in the complex interaction with the host plants and silverleaf whitefly population dynamics are largely unknown. These areas are high-priority focal points for investigation and clarification in the new research and technology transfer plan.

Although insecticides alone or in combination have been found to provide adequate control on major cultivated crops, insecticide resistance management is a particularly important factor that must be addressed. Other research and action areas of the plan reinforce the need for intensive development of biological and other nonchemical control, disease and silverleaf whitefly resistant plant types, and an expansion of our current knowledge of whitefly and natural enemy taxonomy, physiology, biochemistry, and genetics.

## Introduction

The year 1996 marked the close of the 5-year sweetpotato whitefly strain B (= silverleaf whitefly) national research and action plan developed by USDA agencies, state agricultural experiment stations, and commodity-involved industries. The plan focused on developing methodology for whitefly control and management. A USDA Coordinating Group (two members from ARS, two members from APHIS, two members from CSREES, and one member from SAES) was formed to help ensure a unified effort for the program, and provided for an annual review to exchange research information, plan cooperative work, and evaluate research progress.
*Bemisia tabaci* was of little concern in the United States until the late 1970's when epidemic outbreaks began to occur at sporadic intervals. Outbreaks continued through the 1980's on an increasing number of cultivated and weed hosts. The transition from *B. tabaci* to *B. argentifolii*-infested agricultural systems in Arizona, California, Texas, and Florida appears to have occurred during the mid-to late-1980's. Economic losses from *B. argentifolii* have involved cotton and a wide range of ornamentals, melons and vegetable crops. Conservative estimates suggest that losses in the agricultural communities exceed $500 million annually.

Within the framework of the 5-Year National Research and Action Plan, the combined efforts of participating federal and state agencies and the agricultural industries have provided solutions to the urgent need for short-term control technologies and established the groundwork for long-term management. Losses in agricultural communities where the silverleaf whitefly is a factor in crop and horticultural production have not increased and in most cases have decreased. Significant research progress has resulted in a number of management tools adopted in crop production systems. Long-term economically, socially, and environmentally acceptable management systems are being developed from the extensive knowledge base developed to provide a more complete understanding of whitefly biology, ecology, and host plant interactions.

Cooperative extension and education activities have played a vital role in implementation and communication of silverleaf whitefly research outcomes and management technology through communications networking and improved efforts to provide information and management strategies to producers.

The whitefly complex continues to be a serious problem. The second 5-year plan "Silverleaf Whitefly, *Bemisia argentifolii*, Bellows and Perring: Research, Action, and Technology Transfer Plan (1997-2001)" provides the mechanism and organizational entity to maintain continuity and a continuing high level of coordinated research and technology transfer.

**Table 1. Numbers of Research Reports for the 1998 Silverleaf Whitefly Annual Progress Reviews of the USDA Silverleaf Whitefly National Research, Action and Technology Transfer Plan (1997-2001).**

| | Research Priorities[a] | | | | | | |
|---|---|---|---|---|---|---|---|
| Agency[b]/State | A | B | C | D | E | F | Total |
| | 1998 Review, Charleston, SC | | | | | | |
| APHIS | | | | 11 | | 2 | 13 |
| ARS | 12 | | 6 | 13 | 6 | 1 | 38 |
| AZ | | | 1 | | | 2 | 3 |
| CA | 1 | 1 | 7 | 5 | 6 | 3 | 23 |
| FL | 1 | 1 | | | 1 | | 3 |
| GA | | | | | 1 | | 1 |
| NY | | | | | | | |
| OH | | | | | | | |
| TX | | | | 2 | | | 2 |
| OTHERS | 3 | | | 1 | 1 | 1 | 6 |
| TOTAL | 17 | 2 | 14 | 32 | 15 | 9 | 89 |

[a] A = Biology, Ecology, and Population Dynamics; B = Viruses, Epidemiology and Virus-Vector Interactions; C = Chemical Control, Biopesticides, Resistance Management, and Application Methods; D = Natural Enemy Ecology, and Biological Control; E = Host-Plant Resistance, Physiological Disorders, and Host Plant Interactions; F = Integrated and Areawide Pest Management Approaches, and Crop Management Systems.

[b] APHIS = USDA, Animal and Plant Health Inspection Service; ARS = USDA, Agricultural Research Service.

## I. Plenary Session Keynote Address Summaries:

### Section A: Plenary Session Summary

Michael E. Salvucci, Greg Wolfe and Donald L. Hendrix
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Phoenix, AZ.

### Polyol Synthesis as a Mechanism for Thermotolerance in *Bemisia*

The silverleaf whitefly (*Bemisia argentifolii*) thrives in arid regions where daytime temperatures often exceed 45°C. These temperatures are sufficiently high to damage cellular machinery and are generally lethal to most organisms. We have recently found that whiteflies accumulate sorbitol, a polyhydroxy alcohol (polyol), when they are exposed to elevated temperatures (i.e., ≥35°C). Our studies suggest sorbitol functions as a thermoprotectant in whiteflies, a conclusion consistent with the well-known ability of polyols to protect enzymes against heat denaturation. In the present study, we determined the effect of temperature on primary metabolism in the whitefly. In particular, we examined how the various metabolic steps associated with sorbitol synthesis were affected by temperature. Analysis of the body contents and honeydew of whiteflies after feeding on artificial diets containing labeled sucrose showed that more than twice as much label was incorporated into body contents when feeding was conducted at 41 compared to 25°C. Although similar amounts of label were excreted in the honeydew at the two temperatures, a much greater percentage of the label in the honeydew was associated with the monosaccharides glucose and fructose than the disaccharide trehalulose at the higher temperature. Analysis of the honeydew from whiteflies feeding on cotton plants showed a similar effect of temperature on the composition of the honeydew. Measurement of the activities of several glycolytic, pentose-phosphate and polyol pathway enzymes at 42 and 30°C showed that NADPH-ketose reductase/sorbitol dehydrogenase, sucrase, glucokinase and glucose-6-phosphate dehydrogenase activities were stimulated to a greater extent at the higher temperature than trehalulose synthase and fructokinase. $NAD^+$-sorbitol dehydrogenase, the enzyme responsible for sorbitol breakdown, was inhibited at 42°C. At temperatures above 40°C, trehalulose synthase activity was not increased by temperature, whereas sucrase activity was higher. Based on these findings, we propose that at high temperatures metabolic conditions increase the availability of fructose for sorbitol synthesis. High temperatures also appear to stimulate pentose-phosphate pathway activity, the main source of reduced coenzyme for sorbitol synthesis. Thus, sorbitol accumulates in whiteflies because of the greater availability of substrate (i.e., fructose) and coenzyme (i.e., NADPH) at elevated temperatures. Also, elevated temperatures stimulate the activity of NADPH-ketose reductase/sorbitol dehydrogenase, the enzyme that synthesizes sorbitol, but inhibit the activity of NAD-sorbitol dehydrogenase activity, the enzyme that degrades sorbitol.

### Section B: Plenary Session Summary

Robert L. Gilbertson[1], M. R. Sudarshana[1], Hong-Li Wang[2], Yu-Ming Hou[1], Raquel Salati[1], Eduardo Garrido Ramirez[1], and William J. Lucas[2]

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### An Update of the Status of Whitefly-Transmitted Geminiviruses: The Good, the Bad and the Ugly

In addition to the direct damage that the silverleaf whitefly does to crop production, these insects also cause tremendous damage through their vectoring of plant viruses, particularly geminiviruses. Geminiviruses are the only recognized group of plant viruses that have a genome of single-stranded DNA, and these viruses derive their name from their unique twinned icosahedral virions (the Latin word gemini means twin). The Geminiviridae family is composed of three subgroups. Members of two of the subgroups are transmitted by various leafhopper species and possess a monopartite genome, whereas members of the third subgroup are transmitted by whiteflies (*Bemisia tabaci* and *B. argentifolii*) and usually possess a bipartite genome. Diseases caused by whitefly-transmitted geminiviruses are generally found in tropical and sub-tropical areas and afflict crops such as tomatoes, melons, beans, peppers, and cassava. Disease symptoms vary, but include stunted and distorted plant growth and golden or yellow mosaics and curling and/or crumpling of leaves.

Whitefly-transmitted geminiviruses represent an emerging group of plant viruses in that they were only recognized as pathogens 20 years ago, but today over 60 distinct viruses have been described and more are being identified annually. Moreover, these viruses infect are wide range of crop and weed plant species. However, in contrast to some viruses that are able to infect a wide range of plant species (e.g. cucumber mosaic virus), whitefly-transmitted geminiviruses have relatively narrow host ranges. However, these viruses have demonstrated a capacity for rapid evolution as well as the capacity to be spread long distance in association with plants or whiteflies (geminiviruses are not seed-transmitted). These properties have led to the rapid emergence of these viruses.

One of the mechanisms by which new geminiviruses appear is through the adaptation of an indigenous weed-infecting geminivirus to a crop plant. An example of this is the appearance of tomato mottle geminivirus (ToMoV) in Florida. This virus was first observed in tomatoes in Florida in the late 1980s, and it causes stunted plant growth, leaf mottling, and yield losses. The viral DNA was cloned and sequenced, and phylogenetic analyses of the ToMoV DNA sequences revealed that this was a new geminivirus, which was most closely related to bean dwarf mosaic geminivirus (BDMV) and abutilon mosaic geminivirus (AbMV). Interestingly, the AbMV is closely related to a geminivirus that infects the common weed, Sida spp., in Florida. Thus, it is believed that the geminivirus from Sida was introduced into tomatoes by whiteflies and became host-adapted to tomato. Moreover, this is believed to be occurring on a regional basis wherever whiteflies and indigenous geminiviruses occur and can explain the appearance of distinct geminiviruses causing similar symptoms in a given crop plant in different geographical locations. This may also have been facilitated by the introduction and spread of the silverleaf whitefly, which has a broader host range and may move between weeds and crop plants more readily.

Another mechanism by which geminiviruses have appeared in areas where they were not known to occur previously has been through the movement of viruliferous whiteflies and or infected plant materials. The introduction of tomato yellow leaf curl geminivirus (TYLCV) into the Dominican Republic is an excellent example of this. In late 1992, unusual virus-like symptoms were observed on tomato plants in the DR. By the 1993 growing season, entire fields were being lost to this virus and by the 1994 season the entire processing tomato industry was threatened. Using the polymerase chain reaction and DNA sequencing, this virus was identified as TYLCV in 1994. Using a TYLCV DNA probe and squash blot hybridization, it was established that the virus had spread throughout the island, but was predominantly found in tomato. This led to the establishment of a three month whitefly-host free period in the DR that together with the use of insecticides and TYLCV tolerant varieties has led to the effective management of the disease. The effect of the host-free period was dramatically demonstrated by PCR analysis of whiteflies collected at monthly intervals in the DR. By the end of the tomato growing season, all whitefly samples from all locations were positive for TYLCV. However, by two months into the host-free period the virus could barely be detected in any whitefly sample. Thus, although TYLCV continues to pose a threat to tomato production in the DR, it is presently being kept at low enough levels early in the season to allow for acceptable yields.

The capacity for rapid evolution in whitefly-transmitted geminiviruses has been demonstrated by pseudorecombination and intermolecular recombination between ToMoV and BDMV. In most cases, it has been impossible to make pseudorecombinants between distinct geminivirus species. However, this has been accomplished for the closely related ToMoV and BDMV. Plants infected with the pseudorecombinants showed mild symptoms and had low levels of DNA-B. This suggested that the pseudorecombinants were defective in some function. However, upon passage of one of these pseudorecombinants (ToMoV DNA-A and BDMV DNA-B) through plants, the plants developed severe symptoms. Genetic analysis revealed that an intermolecular recombination event had occurred in which the origin of replication (the common region) of BDMV DNA-B had been replaced with that of ToMoV and that this resulted in increased levels of DNA-B. Pseudorecombination and intermolecular recombination are likely to be mechanisms for evolution of new geminiviruses in the field.

Another objective of our laboratory is to develop a thorough understanding of how BDMV spreads within its plant host. This involves a precise examination of how the virus moves out of the initially infected cell (cell-to-cell movement), and the determination of the exact cell and tissue types this type of virus infects as it spreads both cell-to-cell and long distance through the plant. To follow viral movement, the viral coat protein gene was replaced with the green fluorescent protein (GFP) gene. The BDMVA-GFP replicated in a tobacco protoplast system to levels similar to the wild-type virus and expressed GFP. The BDMVA-GFP was then introduced, together with the wild-type DNA-B component, into beans via particle bombardment. The BDMV-GFP induced symptoms in bean plants, indicating that it had spread long-distance through the plant. We next examined the pattern of GFP fluorescence using fluorescence microscopy and confocal laser scanning microscopy. In the radicles of bombarded seedlings, GFP was evident in single cells by 12 hours after inoculation. By 24-48 hours, clusters of fluorescent cells could be observed, indicating that the virus had begun to move cell-to-cell. By 24 hours, the virus was moving through cortical cells toward the phloem and by 48 hours the virus had reached the cells of the phloem. Interestingly, the virus appeared to move specifically toward the phloem. Once the virus had entered cells of the phloem, it moved rapidly toward the root. Infections in the roots were confined to cells of the phloem. On the other hand, there was a continuous line of green fluorescent cells from the point of inoculation up toward the shoot apex, showing that the virus may have moved both cell-to-cell and long distance. In stems and petioles, the virus was limited to cells of the phloem. In primary and trifoliolate leaves, BDMV was found to infect cells of all vein

orders. The virus was also found to exit from phloem tissues into non-phloem cells, and this depended on the stage of development of the host. Finally, green fluorescence in reproductive tissues indicated that the virus had infected flower, pod, and seedcoat tissues but was excluded from the embryo. This later finding is consistent with the fact that geminiviruses are not seed-transmitted. Thus, through the use of the BDMV-GFP we were able to follow the movement of the virus from the seedling through the complete life cycle of the plant. This BDMV-GFP system also was used to examine the resistance of a pinto bean cultivar (cv. Othello) to BDMV infection. The results revealed that the resistance response involved the hypersensitive reaction, and that this occurred at or around the time the virus had accessed the cells of the phloem. Identification of the genes involved in this resistance response could lead to new approaches to generating gemini virus-resistant plants.

**Section C: Plenary Session Summary**

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**Understanding Insecticide Resistance in *Bemisia***

Management of insecticide resistance in *Bemisia* requires effective techniques for detecting resistance in its early stages of development. The use of bioassay and biochemical techniques have now become standard practice, although the relative contributions of each to the study of resistance vary considerably. Bioassays are essential to characterize the resistance status of pest populations, as well as to determine the efficacy of potential replacement insecticides for those no longer of use.

Synergists are often applied in bioassays with insecticides to inhibit detoxification enzymes, and they can thus be used to indicate the presence of specific resistance mechanisms. There is little doubt that synergists provide important information in studies of resistance, but it is imperative that their use be thoroughly validated by biochemical studies.

Biochemical and molecular techniques are now well established in resistance studies for some of the more important pests, including *Bemisia.* These techniques are aimed directly at the level of the resistance mechanism and are capable of accurate identification of resistant genotypes, thus making them especially useful for monitoring changes in the frequencies of resistance alleles in populations of *Bemisia* under different insecticide selection regimes. In a *Bemisia* population from cotton in Israel, the combined use of bioassay and biochemical techniques showed that insensitivity of the enzyme acetylcholinesterase (AChE) was responsible for resistance to organophosphorus (OP) insecticides. This was confirmed in field-simulation studies where OP insecticide applications rapidly selected the insensitive AChE variant from a mixed population of insects initially containing equal frequencies of a sensitive AChE and the insensitive AChE. With careful assessment, this approach can provide valuable information on the dynamics of resistance, leading ultimately to improved pesticide recommendations for management of *Bemisia.*

**Section D: Plenary Session Summary**

Mark S. Hoddle, Department of Entomology, University of California, Riverside, CA 92521.

**Biological Control of *Bemisia argentifolii*: Using Functional Response Assays and Lifetables to Determine Parasitoid Efficacy in Greenhouses.**

Silverleaf whitefly (*Bemisia argentifolii* [Homoptera: Aleyrodidae]) is the major foliar pest attacking poinsettias (*Euphorbia pulcherrima*) in the United States. The ability of parasitoids (Hymenoptera: Aphelinidae) to control *B. argentifolii* in small experimental and large commercial greenhouses have been investigated as potential components of an integrated pest management program for this pest.

Two parasitoids have been studied in greenhouses; *Eretmocerus eremicus* and a *Bemisia* adapted strain of *Encarsia formosa* from Beltsville Maryland. The ability of these two species to find and attack *Bemisia argentifolii* was determined. Experiments were conducted with whitefly patches on single leaf poinsettia plants randomly distributed in canopies of four commercially grown poinsettia crops at an early and late stage of plant growth. *Eretmocerus eremicus* found experimental patches in canopies of small and large plants more quickly and frequently, and killed more nymphs following patch discovery than *Encarsia formosa* (Beltsville strain). *E. eremicus* exhibited a Type I functional response in small and large canopies while *E. formosa* (Beltsville strain) showed a Type II functional response in small canopies and a weak linear response in large canopies. In greenhouses treated with *E. eremicus*, canopy size increased 4.6x and nymphs per plant increased 14.2x between small and large canopy experiments. Consequently, area of search for this parasitoid increased 83%, number of wasps counted on patches decreased 74%, and proportion of nymphs killed

in artificial patches decreased 47% between small and large canopies. In greenhouses treated with *E. formosa* (Beltsville strain), canopy size increased 7.3x and nymphs per plant increased 25.4x between small and large canopy experiments. Consequently for *E. formosa* (Beltsville strain), area of search increased 11%, number of wasps counted on patches decreased 86%, and proportion of nymphs killed in artificial patches decreased 47% between small and large canopies.

Concurrent construction of lifetables and population counts of *B. argentifolii* nymphs and adults on plants in experimental greenhouses confirmed that *E. eremicus* was more effective at controlling *B. argentifolli* population growth. At a release rate of three female parasitoids per plant per week, ifetables indicated that in *E. eremicus* greenhouses mortality of numbered nymphs ranged 70-98% and parasitism was 21-25%. In *E. formosa* (Beltsville strain) greenhouses mortality ranged 60-81% and parasitism was 8-24%. Naturally occurring mortality in control cages which excluded parasitoids ranged 7-23%. Cuttings were taken from stock plants in *E. eremicus* greenhouses without any insecticide applications being applied. Trials with *E. formosa* (Beltsville strain) had to be terminated and insecticides applied because of unacceptable whitefly population growth.

## Section E: Plenary Session Summary

D. Michael Jackson.
USDA-ARS, U. S. Vegetable Laboratory, Charleston, SC

### Plant Resistance to Whiteflies: Lessons from the Past - Directions to the Future

The Silverleaf Whitefly (SLWF) is extremely polyphagous and it has a high capacity for adapting to new host plants. However, SLWF does not infest all plant species, and some plants are inferior hosts. Even within germplasm sources for major crops there are genotypes resistant to SLWF. The hostÄplant resistance approach to managing SLWF has many advantages, including reduced environmental risks, lessened worker exposure, compatibility with biological control agents, enhanced consumer acceptance, and possible economic advantages. There are also disadvantages to the plant resistance approach, including the extensive research time, effort, and resources necessary to develop insect-resistant cultivars, possible poorer yields or quality than standard cultivars, susceptibility to different pests, and the potential that resistance will "break down" under high insect pressure. This possibility alone has led some to call into question the wisdom of pursuing the plant resistance approach for this pest species. Can we produce whiteflyÄresistant cultivars with lasting or sustainable resistance to SLWF? Although the extreme polyphagy of this pest will make management of resistant cultivars difficult, it is likely that resistant germplasm can be deployed and sustained with a reasonable amount of managerial input. However, researchers must carefully examine their particular cropping situation to determine if the cost to benefit ratio is sufficient to warrant proceeding with a hostÄplant resistance breeding program. Whitefly injury is expressed in several distinct ways, and thus there are independent mechanisms of plant resistance to counter them. Resistance mechanisms for reducing direct feeding damage typically are directed at preventing SLWF populations from reaching epidemic proportions. Development strategies typically utilize antibiosis and antixenosis factors that affect whitefly biology and behavior. On the other hand, strategies for resistance against whiteflyÄtransmitted viruses or physiological plant disorders are typically different and independent from those aimed at reducing direct feeding damage. Because non-persistent viruses and physiological disorders can be produced by low numbers of SLWF, resistance mechanisms that reduce whitefly populations are of limited use. Reported mechanisms of resistance to SLWF include manipulation of phloem nutrition or pH, leaf shape, density of leaf hairs, trichome exudates, proximity of vascular bundles to the leaf surface, thickness of the mesophyll tissue, leaf color, leaf reflectance, enhanced biological control, early maturity, and tolerance. Abiotic factors, such as temperature, rainfall, and sunlight, affect how a resistant cultivar will respond once it is planted in the field. The condition, phenology, and age of a plant also affect how it will withstand a whitefly attack. Factors associated with the insect, including biotype, population dynamics, and hostÄplant history, are also very important. Also, the presence or absence of biological control agents should be taken into consideration in management decisions. Deployment strategies for pest-resistant cultivars should rely on theories developed for management of insecticide resistance, sustainability of transgenic insecticidal cultivars, and maintenance of conventional pest-resistant cultivars. The technique of planting mixtures of susceptible and resistant cultivars has a sound theoretical basis, and with this method the relative fitness of the RS and SS genotypes can be improved relative to the homozygous resistant genotype. In multi-gene situations in which resistance factors are pyramided into a single cultivar, the relative fitness differentials between resistant and susceptible genotypes can be reduced even further. In most cases, the development of physiological or behavioral adaptations to resistant germplasm will have an associated fitness cost. Thus, in the absence of resistant plants the new biotype should have a lower fitness than the non-adapted strain. Therefore, in many situations the development of biotypes is reversible. However, we must be willing to put forth the management efforts necessary to sustain the usefulness of

our resistance resources. The most powerful tool for managing whitefly resistance resources is an understanding of the agronomic system to which it will be used, and in integrating this technology into a complete management system for this pest.

## Section F: Plenary Session Summary

Steve H. Husman & Larry Jech
University of Arizona, Cooperative Extension

### Improved Areawide Whitefly Management Through Voluntary Industry and Extension Partnership

Cotton producers, Pest Control Advisors (PCA), and University of Arizona (UA) Cooperative Extension personnel formulated and coordinated areawide whitefly management strategies in the production area near Gila Bend, AZ., from 1995-1997. In 1995-1996, the project encompassed approximately 10,000 and 6000 acres, 10 and 8 producers, and 6 PCA's respectively. In 1997, the project was expanded upon request from producers in an adjacent production area and included approximately 18,000 acres, 14 producers, and 9 PCA's. Project goals were to implement coordinated and standardized whitefly sampling and control strategies, develop areawide population distribution dynamics, reduce insecticide applications through utilization of sound scientific whitefly sampling techniques and treatment threshold utilization, and encourage areawide cooperation and communication.

Producers were assessed $3.00/acre with the monies used to hire local students for field scouting and transportation needs. An economic development grant provided by the Electrical District #8 supported the project coordinator's salary who is a University of Arizona employee. The field scouts were trained by UA personnel to use the recommended whitefly leaf turn sampling technique. In 1995, adult counts were made with treatment threshold recommendations of 3-5 adult whiteflies per leaf. In 1996 and 1997 adult and nymphal sampling was conducted with a treatment recommendation threshold of 3-5 adults per leaf (or 40-57% of 5th mainstem node leaves infested with 3 or more adults) and 1 large nymph per disk (or 40% of 5th mainstem leaf disks [3.88 $cm^2$) infested with 1 or more nymphs). The project area was divided into quadrants with every field sampled a minimum of once weekly. Daily field counts were entered in a computer spreadsheet database with daily data transferred by fax to responsible producer and PCA. Treatment thresholds and chemistry use and rotation suggestions were made by Cooperative Extension with final decisions and material choice at the discretion of the producer and PCA. Weekly community meetings were held and used to discuss both areawide and field specific population dynamics, treatment suggestions, and general cotton production issues.

In 1995, whitefly pressures were extremely high with an average of 5.2 per acre whitefly treatment application made areawide with a range 3-13. Control was unacceptable even with the numerous applications. Resistance development was documented by UA personnel offering explanation relative to apparent areawide control failure. In 1996, a Section 18 granted the use of new novel chemistry consisting of two Insect Growth Regulators (IGR), Applaud and Knack. Successful areawide education targeted at successful use and deployment of the IGR chemistry resulted in a reduction of areawide whitefly treatment applications to 1.9 per acre. In 1997, an average of 2.81 whitefly applications per acre were used for successful control. Producers and PCA's have expressed that all of the initial goals have been realized and wish to continue.

## Section A: Biology, Ecology and Population Dynamics

Co-Chairs: Jon Allen and Steve Naranjo

**Investigator's Name(s)**: C.C. Chu, T.J. Henneberry, and E. T. Natwick.
**Affiliation & Location**: USDA-ARS, Western Cotton Research Laboratory, Phoenix, AZ and University of California Coop. Ext., Holtville, CA.
**Research & Implementation Area**: Section A: Biology, Ecology, and Population Dynamics.
**Dates Covered by the Report**: 1996-1997.

### Evaluation of CC Trap Color and Placement in Various Crops

**CC Trap Catches at Three Trap Heights in a Cotton Field in Imperial Valley, California, 1996.**
CC traps were placed 15 cm above the cotton canopy, at the top of canopy, and 15 cm below the canopy top. The study was conducted from 15 July to 12 August in 1996. Results showed that the traps placed 15 cm below the canopy top caught significantly more adult whiteflies than traps placed at the other two trap heights. Adult catches in traps placed 15 cm below the canopy top were significantly correlated to the number of adult whiteflies counted on the 5th main stem node leaves.

**Effect of CC Trap Base Colors on Insect Catches in Cotton, Alfalfa, and Sugarbeet Fields in Imperial Valley, California and Maricopa, AZ, 1996-1997.**
The CC trap consisted of two components: a trap top and a trap base. The trap top is a clear plastic drinking cup. The open cup end fits into a yellow plastic base with a cylinder shape outside and hollow cone inside surface. Tests were conducted in fields in Imperial Valley, California and Maricopa, Arizona in 1996 and 1997 with trap bases of 10 different colors (yellow, white, black, French grey, red, rum, blue, lime green, spring green, woodland green). Results showed that the color lime green caught more adult whiteflies than other colored trap bases. White and blue colored trap bases caught the most thrips. Leafhoppers were also caught in traps with yellow or green trap bases.

**Evaluation of CC Trap Adult Whitefly Catches at Five Trap Heights in a Cotton Field in Maricopa, AZ, 1997.**
In choice and non-choice studies, CC traps were placed 15, 45, 75, 105 and 135 cm above furrows in a cotton field. The studies were conducted from 15 July to 18 September 1997. Highest adult whitefly catches occurred in traps placed at the 75 cm above the furrows on 15 July. Numbers of adult whiteflies caught gradually increased in traps placed at higher levels from late July to mid-September. Adult whitefly catches were closely related to leaf-turn counts from 20 August to 18 September in the choice and the non-choice studies.

**Evaluation of CC Trap Catches at Five Trap Heights on A Bare Ground in Imperial Valley, California, 1996.**
CC trap heights were compared in harvested cotton fields in choice and non-choice studies from August to October 1996. Traps were placed 15, 30, 45, 60, and 75 cm above furrows. Fifteen centimeters was the approximate height of cotton beds in the fields. CC traps are 14 cm high. Adult whitefly catches were highest when the traps were placed at 15 cm high followed by 30, 45, 60, and 70 cm. Number of adults caught with traps at 15 cm high were 32.2 adults/ 24 h for the no-choice study and 19.3 for the choice study, respectively.

**Evaluation of CC Trap Catches at Two Trap Heights in Fall-planted Cabbage and Lettuce Fields in Imperial Valley, California, 1996.**
CC trap catches in a fall-planted cabbage field were compared with traps base placed at 5 or 20 cm above the surface of cabbage beds. Number of adults caught were 42.4 and 26.4 adults/trap/24 h for 5 and 20 cm, respectively. In a fall-planted lettuce field, number of adults caught were 5.9 and 2.7 adults/trap/24 h for 5 and 20 cm respectively.

**Investigator's Name(s)**: C. C. Chu, T. J. Henneberry, and M. A. Boykin.

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**Research & Implementation Area**: Section A: Biology, Ecology, and Population Dynamics.

**Dates Covered by the Report**: 1996 - 1997.

## Response of Silverleaf Whitefly Adults to Low Intensity of White Fluorescent Light

Under laboratory conditions, released whitefly adults moved from a release chamber through plastic tubes to a chamber illuminated with white fluorescent light that was 46 cm distant from the whitefly release point. Numbers of adults that moved to the light source increased when light intensity was increased to 19 lux or higher. Adult movement was minimal when light intensity was 2 lux or the chamber was dark.

**Investigator's Names:** David E. Dean and David J. Schuster

**Affiliation & Location:** University of Florida, Gulf Coast Research and Education Center, Bradenton, FL

**Research & Implementation Area:** Section A: Biology, Ecology, and Population Dynamics

**Dates Covered by the Report:** Spring 1995 - Spring 1996

## Mortality Factors Affecting *Bemisia argentifolii* (Homoptera: Aleyrodidae) on Tomatoes in Florida

Mortality for immature stages of *Bemisia argentifolii* Bellows and Perring was assessed on field tomatoes in Florida using life-tables and exclusion methods to measure the impact of natural enemies. A series of overlapping cohorts of whiteflies was artificially established throughout the fall and spring tomato growing seasons. Whitefly mortality was 33.75% higher in open cohorts than in cohorts with natural enemies excluded. Total mortality for one late season cohort of whiteflies was 90%. Life-table results indicate that mortality attributable to natural enemies varied from 10 to 60% of the total mortality over the growing season. In addition to an effective complex of predators, host feeding by parasitoids may have made an important contribution to whitefly mortality. The incidence of predation expressed in k-values for the egg and fourth instar was significantly correlated with total K (Spearman rank = 0.6813, 0.6923; $P = 0.0103, 0.0087$ respectively). The high reproductive potential of this whitefly species was evident. In spite of high whitefly mortalities inflicted by the natural enemy complex, the whitefly population continued to increase. The contribution of pathogens, parasitoids and predators to whitefly mortality on field tomatoes in Florida was clarified.

**Investigator's Name(s)**: Dan Gerling, Mali Gershon, Tamar Orion, Nelly Namies, and Steffen Reese

**Affiliation & Location**: Department of Zoology, Tel Aviv University, The George S. Wise Faculty of Life Sciences, Ramat Aviv, Israel

**Research & Implementation Area**: Section A: Biology, Ecology, and Population Dynamics

**Dates Covered By The Report**: 1997

## Population Dynamics of Whiteflies on Wild Hosts in Israel

*Bemisia tabaci*, and later possibly also *B. argentifolii* reached extremely high populations in Israel on wild and on cultivated plants. These high population outbreaks abated about 10 years ago, when the pest became less virulent though still prominent and, at times severe. During the high infestation days, *Lantana camara* shrubs were infested with extremely high populations. Being one of the only perennial host species in Israel, they served as important carry-over hosts for *Bemisia* whiteflies, and until this day are unique in being a year-round evergreen host for this pest. Therefore, we set out to determine if the general decline of *Bemisia* in Israel is reflected in populations on lantana, and to see whether one can learn more about the factors controlling this pest. From early April until October, each of 22 sites in which lantana grew wildly were visited. Eleven sites were north of Tel Aviv and 11 to the south. Each plant was sampled twice, a one branch sample was taken for microscopic observation, and several branches were taken for whitefly and parasitoid emergence. From the first sample, we selected 10 leaves for the determination of whitefly and parasitoid and the presence of predators. From the second sample, we removed 100 leaves that were placed in emergence bottles and kept for 1 month. Thereafter, the vials on top of the bottles were removed and all whiteflies and parasitoids therein were counted. In addition, we placed 2-5 potted cabbage plants, each heavily infested with the pest, under the lantana shrub during each visit. This was done to augment the *Bemisia* population and to determine if this technique could reveal which natural enemies would drive it back down, if at all. An artificial build-up of whitefly populations would also serve as a convenient place for future releases and acclimatization of introduced natural enemies.

The results showed that, in spite of our massive introduction of whiteflies, their populations usually remained very low, with but occasional rises to more than 6 nymphs per leaf. A few exceptions occurred, but these showed normal build-up, i.e. a population rise from August on with no affect of the releases of more than 10.000 adults each fortnight from mid April on. Parasitoids existed throughout the study and % parasitism fluctuated widely. The main species found were *Eretmocerus mundus* and *Encarsia lutea*, but some *Encarsia pergandiella* and *Encarsia inaron* were also recovered. *E. pergandiella* was typical to one region in the vicinity of Tel Aviv.

**Investigator's Name(s):** D.L. Hendrix, M.E. Salvucci, and G.R. Wolfe.

**Affiliation & Location:** USDA-ARS-WCRL, Phoenix AZ.

**Research & Implementation Area:** Section A: Biology, Ecology and Population Dynamics.

**Dates Covered by the Report:** January 1997 – December 1997.

## Polyol Metabolism in *Bemisia argentifolii*

The silverleaf whitefly, *Bemisia argentifolii* Bellows and Perring, accumulated high levels of sorbitol in its hemolymph. Accumulation of this polyol occured in a diurnal pattern. The greatest sorbitol concentrations in the hemolymph (ca. 450mM) were found in the early afternoon in insects collected from fields of upland cotton (*Gossypium hirsutum* L.). Hemolymph concentrations during early morning hours were found to be approximately 10-fold lower than in the early afternoon. In laboratory and greenhouse experiments, elevated temperature (>35°C) stimulated this polyol accumulation. Increasing the concentration of sucrose in the insect's diet also increased its accumulation of sorbitol. Assay of enzymes extracted from adult insects showed that hemolymph sorbitol was produced from fructose by an unusual ketose reductase. This enzyme utilized NADP(H), unlike enzymes in most other organisms which convert fructose to sorbitol using NAD(H) as a cofactor. Fructose employed in this reaction originated from sucrose in the insect's diet. In contrast, other insect systems such as the silkworm, *Bombyx mori* L., synthesize sorbitol during diapause from glucose originating from glycogen using an aldose reductase. At the end of diapause, such insects convert accumulated sorbitol to fructose. We could not detect interconversion of glucose and sorbitol in *B. argentifolii*. In addition, we found only traces of sorbitol in the honeydew of this insect. This suggests that at the end of the day when sorbitol in the hemolymph decreased, sorbitol was converted back to fructose rather than being excreted. Insects living upon water-stressed plants had greater levels of hemolymph sorbitol than insects on well-watered plants. Insects were also much more resistant to high temperature (ca. 40°C) when allowed to feed and accumulate sorbitol, than those prevented from feeding. This suggests that sorbitol accumulation in this insect is a physiological adaptation for survival in its hot, dry environment.

**Investigator's Name(s):** T. J. Henneberry, L. Forlow Jech, and D. L. Hendrix.

**Affiliation & Location:** USDA-ARS, Western Cotton Research Laboratory, Phoenix, AZ.

**Research and Implementation Area:** Section A: Biology, Ecology, and Population Dynamics.

**Dates Covered by the Report:** 1995-1996.

## Seasonal Distribution of *Bemisia argentifolii* (Homoptera: Aleyrodidae) Honeydew Sugars on Cotton Lint

Cotton lint stickiness caused by insect honeydew deposits is a significant problem in the textile industry. We conducted studies to determine the accumulation of honeydew sugars and thermodetector counts on open cotton bolls during the season. Numbers of open bolls for DPL decreased dramatically by 15 September reflecting termination of the first fruiting cycle. Trehalulose and melezitose sugars produced by *B. argentifolii* were found on lint for all weekly boll samples. About 95% of the open cotton bolls occurred by mid-September. This suggests that defoliation timing and early harvest can be important management tools to avoid sticky cotton. For upland cotton extending the cotton season after 95% of the crop matured (≅ 15 September) resulted in development from non-sticky cotton to lightly-sticky cotton within 21 days following the occurrence of increasing whitefly populations after 15 September. This could have been avoided with mid-September defoliation. At harvest, total amounts of trehalulose and melezitose and total thermodetector counts for all weekly harvests were greater than amounts found in lint for randomly selected 20 boll samples, and samples from all cotton picked from 4 m of row, except for thermodetector counts for spindle-machine-picked cotton. This probably occurred because weekly picked cotton escaped rainfall, exposure to other weathering, and machine-picked cotton contains more honeydew-contaminated leaf trash. Except in one instance, thermodetector count and lint trehalulose and melezitose content for all sampling methods were significantly correlated.

**Investigator's Name(s):** T.J. Henneberry[1], L. Forlow Jech[1], D.L. Hendrix[1] and D.E. Brushwood[2].

**Affiliation & Location:** [1]USDA-ARS, Western Cotton Research Laboratory, Phoenix, AZ and
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**Research and Implementation Area:** Section A: Biology, Ecology, and Population Dynamics.

**Dates Covered by the Report:** 1997.

## Lint Stickiness and *Bemisia argentifolii* (Homoptera: Aleyrodidae) Populations

We conducted studies using insecticide treatments to regulate whitefly populations and determine relationships to cotton lint stickiness. Insecticide applications reduced number of whiteflies, thermodetector counts and associated honeydew sugars extracted from lint. Increases in thermodetector sticky cotton counts and trehalulose and melezitose were significantly correlated to increasing *B. argentifolii* nymph and adult populations. Sticky cotton counts did not reach levels of concern (5 or >) until adult leaf-turn counts were 7 to 12 or when nymphs were 1.7 to 2.8 per $cm^2$ of leaf disk during the open mature cotton boll period. The action resulting in reduced honeydew sugars by rainfall appears to be dissolving of the sugars and runoff as opposed to increased microbial activity that causes degradation of the sugars.

**Investigators' Name(s)**: T. J. Henneberry, L. Forlow Jech, R. A. Burke, M. J. Panter, and S. F. Faulconer

**Affiliation & Location**: USDA-ARS, Western Cotton Research Laboratory, Phoenix, AZ

**Research & Implementation Area**: Section A, Biology, Ecology, and Population Dynamics

**Dates Covered by Report**: Summer, 1997

## Honeydew Produced by Whitefly Adults and Nymphs Sampled From Untreated and Insecticide-Treated Cotton plots

*Bemisia argentifolii* Bellows and Perring adults and nymphs were collected from replicated cotton field plots that were treated with pyriproxyfen, buprofezin, Danitol/Orthene or Endosulfan. Control plots were unsprayed. Adults from each plot were collected before and after treatments using a small handheld car vacuum modified to hold individual plastic collection vials. Adults were confined in modified petri dish cages, each containing a single whitefly-free greenhouse grown cotton seedling. All but one leaf was removed from each seedling. The leaf portion was placed in the petri dish while the stem and roots extended through a hole cut in the petri dish wall into a vial containing water. Nymph-infested leaves with petioles from each plot were collected, returned to the laboratory and adults removed. Field collected leaves with nymphs were trimmed to 2-inch squares and petioles placed in petri dish cages as described for adults. After 48 hours, the bottoms of each petri dish were removed, placed in a freezer and later rinsed with warm water to collect the deposited honeydew. Numbers of living adults and nymphs were counted. Amount of *Bemisia*-produced trehalulose, melezitose, glucose, fructose and sucrose were determined using high performance liquid chromatography (HPLC). Insecticide treatments had no effect on amounts of sugars found in honeydew produced by adults collected from insecticide-treated plots. Similarly, there was no effect on sugars found in honeydew produced by nymphs on excised leaves from insecticide-treated plots. Overall, adults produced more honeydew sugars than nymphs. In most cases, both adults and nymphs produced more trehalulose than melezitose, glucose, fructose or sucrose. Nymphs produced more melezitose than adults.

**Investigator's Name(s):** Moshe Inbar[1], Hamed Doostdar[1], Gary L. Leibee[2]and Richard T. Mayer[1].

**Affiliation & Location:** [1]U.S. Horticultural Research Laboratory, USDA, ARS, 2120 Camden Rd., Orlando, FL 32803-1419. [2]University of Florida. IFAS, CFREC, 2700 E. Celery Ave., Sanford, FL 32703.

**Research & Implementation Area**: Section A: Biology, Ecology, and Population Dynamics.

**Dates Covered by the Report:** January 1, 1997 - December 31, 1997.

## Asymmetric Interspecific Competition Between Whiteflies and Leafminers

Host plants may mediate indirect interspecific interactions among insect herbivores in various ways. It is now well documented that host plant induced-responses to insect herbivores have a defensive function that may reduce further herbivory. It appears that some induced responses involve complex biochemical reactions that are not inducer (insect) - specific and, thus, provide broad protection. Therefore, the role of plant constitutive and induced defenses as mechanisms that reduce interspecific competition among simultaneously feeding generalist herbivores is limited. Since whiteflies induced higher level of defensive compounds including pathogenesis-related proteins, we examined their role in interspecific competition with other herbivores.

The roles of induced responses of tomato, *Lycopersicon esculentum,* in interspecific interactions among two polyphagous herbivores, the silverleaf whitefly *Bemisia argentifolii* (WF*)* and the vegetable leafminer, *Liriomyza trifolii* (LM), were characterized in lab and field experiments. In a whole plant choice experiment, adult LM feeding and oviposition as well as larval survival were reduced by 47.7%, 30.7%, and 26.5%, respectively, for the WF-infested hosts compared with the controls. Early WF infestations also had negative systemic (plant-mediated) effects on LMs. Adult LMs preferred leaves from control plants to leaves of plants that had been previously infested with WFs; no reciprocal effect of LMs on WFs was found. Feeding by *Helicoverpa zea* larvae, that has been shown previously to effect LM performance, had no effect on WF survival and development. LM natural population dynamics were monitored on control and WF-preinfested plants in a field experiment. WF-infested plants were less suitable for LM development with an overall 41% reduction in LM population density.

These results demonstrate asymmetric, direct and plant mediated, interspecific interactions among generalist herbivores feeding simultaneously on the same host. WFs are polyphagous pests that may be found in many parts of the world, occasionally in high densities. Thus, numerous combinations with which they share the same host plant, and interact with other herbivores may be common. The fate of the interactions between WFs and other herbivores will probably depend on the host plant species, WF density, and the timing of interactions. We suggest that host plant manipulation that reduces interspecific competition may act as an additional mechanism that increases WF success.

**Investigator's Name(s):** Moshe Inbar, Hamed Doostdar and Richard T. Mayer.

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**Research & Implementation Area**: Section A: Biology, Ecology, and Population Dynamics.

**Dates Covered by the Report**: January 1, 1997 - December 31, 1997.

## Local and Systemic Effects of Whiteflies on Tomato Photosynthesis and Phytochemistry

The dynamics of local and systemic effects of the silverleaf whitefly (*Bemisia argentifolii*) nymphs on tomato (*Lycopersicon esculentum* cv. 'Lanai') photosynthesis and Phytochemistry were quantified. The top leaves of 5-week-old plants were covered with gauze sleeves to prevent whitefly feeding. Plants were infested with adult whiteflies for 3 days, then all adults and sleeves were removed. These conditions yielded 6.1 ± 1.9 nymphs/cm$^2$ leaf area. The preinfested and control whitefly-free plants (that were treated similarly) were placed in a growth chamber (12:12 L/D, 80% RH, 23$^0$ C). As an indication of plant stress and photosynthesis efficiency, we measured the chlorophyll fluorescence level of dark-adapted plants. The ratio of variable to maximal fluorescence (Fv/Fm, in relative units) was measured for intact leaves in positions #4 (whitefly infested) and #5 (first clean leaf above the infested ones) from the bottom of the plant using a chlorophyll fluorometer (OS5-FL, Opti-Sciences, MA). Starting from the fifth day after infestation and throughout the experiment (27 days), Fv/Fm (that represents the efficiency of photosystem II) was significantly lower in the whitefly infested leaves. In leaf position # 4 (local effects), both the control and the infested plants had initial Fv/Fm values of 0.84 that gradually declined with leaf aging. However, whitefly infestation accelerated leaf senescence. An Fv/Fm value ≥ 0.8 is considered as an indicator of high photosynthesis efficiency; control plants ended with Fv/Fm values of 0.805 and therefore maintained a high photosynthetic efficiency throughout the experiment. The Fv/Fm values for whitefly-infested leaves dropped below 0.8 at day 19 and ended at 0.788. The systemic effects (leaf #5) on photosynthetic efficiency were not significant. Although from day 2 on, clean leaves on whitefly-infested plants had lower Fv/Fm values than those for control plants, the differences were not significant and Fv/Fm values did not drop below 0.8.

The levels of pathogenesis-related (PR) proteins were measured in a similar experiment. Tomato plants fed on by whiteflies for three weeks had higher levels of PR-proteins both locally and systemically. The levels of beta-1,3-glucanase, chitinase, peroxidase, and lysozyme were increased 2- to 4-fold in the infested leaves (#4) compared with the control leaves. The only exception was that the local induction of peroxidase was not statistically significant. The levels of all PR-proteins that were measured increased systemically. However, total protein levels were not significantly changed either locally or systemically

These results demonstrate that the effect of whiteflies on the host plant photosynthesis occur only few days after larval feeding. Furthermore, moderate infestation levels, as in this experiment, may accelerate early leaf degradation and senescence by 10 to 14 days. However, the effect of whiteflies on plant photosynthesis efficiency, unlike on leaf biochemistry (e.g., the levels of proteins), are locally restricted and do not have a systemic expression.

**Investigator's Name(s):** Rufus Isaacs[1] and David N. Byrne[2].

**Affiliation & Location:** [1]Department of Entomology, Michigan State University, Lansing, MI [2]Department of Entomology, University of Arizona, Tucson, AZ.

**Research & Implementation Area:** Section A: Biology, Ecology, and Population Dynamics.

**Dates Covered by the Report:** 1995 - 1996.

## Aerial Distribution of *Bemisia*

Field studies were conducted in Yuma, Arizona during the summers of 1995 and 1996 to investigate the aerial distribution of *Bemisia tabaci* (biotype B). A population of whiteflies on cantaloupe melon were marked with fluorescent dust during the evening, and samples were taken the next morning. Insects were trapped at four heights between 0 and 7.27 m above fallow ground, and at six distances between 0 to 100 m from the insect source. Trapping was during a 2-3 h period after the initiation of flight activity on eight separate occasions when conditions were suitable for trapping. During these days, a total of 37,685 marked whiteflies were trapped and sexed. The egg-load of the females was also recorded on days when the aerial density was sufficiently great to catch enough insects in the upper traps.

Analysis of the trap catch data revealed a clear negative exponential relationship between height and aerial distribution, and a slightly weaker negative power relationship between distance and aerial distribution. These relationships provide equations that may be employed in concert with detailed meteorological information to provide predictions of whitefly dispersal processes. We also caught marked insects in the uppermost traps adjacent to the source, indicating that a portion of the population had a strong capacity for ascent out of the flight boundary layer. Egg-load was found to decrease with the height, but not the distance from the source field, at which *B. tabaci* was trapped. Mean egg-load close to the ground was significantly greater than that for those trapped at 4.8 and 7.2 m, supporting the hypothesis that there is a trade-off between flight and oogenesis in weak-flying insects. Air temperatures during the trapping periods were positively correlated with the proportion of male and female *B. tabaci* caught in the highest traps, but not in the most distant traps.

**Investigator's Name(s):** Steven E. Naranjo[1], Peter C. Ellsworth[2], and Jonathan W. Diehl[2].

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**Research & Implementation Area**: Section A: Biology, Ecology, and Population Dynamics.

**Dates Covered by the Report:** June 1997 - September 1997.

## Comparative Life Table Studies of *Bemisia* under Different Management Strategies in Cotton

As part of a continuing study to evaluate and demonstrate strategies for *Bemisia* management we quantified *in situ* sources of mortality of immature whitefly stages in untreated plots and in plots under three different insecticide regimes (buprofezin followed by pyriproxyfen, pyriproxyfen followed by buprofezin, and a rotation of conventional materials). Each treatment was replicated 4 times in 0.27 hectare plots. Whitefly populations were monitored weekly and all insecticides were applied according to recommended action thresholds. Life table studies were conducted in replicate plots during 4 periods over the season.

Cohorts of eggs and settled 1st instar nymphs were established from natural populations in each of 16-20 plots in late-July, mid-August and late-August. An initial analysis also was conducted on cohorts established in clip-cages during late June before natural populations had colonized our plots in sufficient numbers to establish the study. Cohorts consisted of approximately 50 individuals of each stage in each plot. The location of individuals on leaves was marked with a non-toxic felt-tip pen. The fate of each individual was then tracked by visual observation with a hand lens every 2-3 days. We attempted to estimate mortality due to insecticides, predators, parasitoids, and weather.

Analyses are underway and only preliminary results for nymphs are reported. Prior to the use of any insecticides for pest control in late-June to early-July, parasitism averaged 5%, sucking predation averaged 42%, and 38% disappeared (likely due to chewing predation). Approximately 16% of the nymphs survived to adulthood. During the 2 weeks following the first pesticide applications in late July, similar values were observed in untreated control plots except that adult emergence averaged < 4%. In plots treated with conventional insecticides, sucking predators killed an average of 24% of the nymphs and insecticides killed about 47%. This is contrasted with pyriproxyfen-treated plots where sucking predation accounted for 36% of all nymphs killed and only 24% were killed by the insecticide. Results for buprofezin treated plots were similar except that a greater number of nymphs were killed by insecticides (59%). Regardless of treatment, adult emergence was extremely low (0-1%) as was mortality due to parasites (0-1%). A large number of nymphs also were dislodged from leaves (19-38%) probably due to a combination of weather (wind and rain) and chewing predation. Three to four weeks following the first insecticide applications (mid-August) levels of sucking predation increased in plots treated with insect growth regulators (33-43%) where additional sprays were not needed. Sucking predation remained lower in conventional insecticide plots (23%) where a second spray was needed the first week in August. Adult emergence (1-8%) and parasitism (2-4%) increased slightly in all plots. Dislodgment was again a major mortality factor (43-49%). Levels of mortality factors in the untreated plots were similar to those observed during the 1st and 2nd observation periods. During the final period beginning in late August only untreated plots were studied. Here sucking predation declined (37%) and adult emergence increased (23%). Once again parasitism was very low (3%).

Additional analyses will focus on evaluating mortality forces in relation to pest density. We also plan to estimate marginal attack rates which will provide a more accurate assessment of mortality by each factor when these factors act contemporaneously. These marginal rates will also be essential in comparative analyses across management regimes.

**Investigator's Name(s):** Dennis R. Nelson, James S. Buckner, Thomas P. Freeman[1], Dan Gerling[2], Moshe Guershon[2], and Gregory P. Walker[3].

**Affiliation & Location:** Biosciences Research Laboratory, USDA-ARS, Fargo, ND 58105; [1]Electron Microscope Facility, Department of Plant Pathology, North Dakota State University, Fargo, ND 58105; [2]The George S. Wise Faculty of Life Sciences, Tel Aviv University, Ramat Aviv, Israel; [3]Department of Entomology, University of California, Riverside, CA 92521.

**Research & Implementation Area:** Section A: Biology, Ecology, and Population Dynamics.

**Dates Covered by the Report:** 1997.

## Surface Lipid Composition of *Aleyrodes singularis* and Comparisons with Other Whitefly Species

The whitefly, *Aleyrodes singularis*, infests a weed, *Lactuca serriola*, in Israel. It is unique in 2 ways: the molted exuviae accumulate and remain on top of the nymph, and the adults periodically distribute waxy particles over the nymphs (Guershon and Gerling, 1994). Both behaviors interfere with parasitism by *Encarsia*. We have characterized the waxy particles and cuticular lipids of the adults and compared them with other species of adult whiteflies.

Gas chromatographic-mass spectrometric analysis of the chloroform soluble surface lipids showed the 3 major components were alcohols, aldehydes and wax esters. Thus, the composition of these lipid classes was similar to that previously observed for *Bemisia argentifolii*, *Bemisia tabaci* and *Trialeurodes vaporariorum* (Buckner et al., 1994; Nelson et al., 1994), *Aleuroplatus coronata, Aleurothrixus floccosus, Aleurotithius timberlakei, Dialeurodes citri, Dialeurodes citrifolii* and *Parabemisia myricae* (Nelson et al., 1997). However, *A. singularis* differed from the others in that it had a significant amount of hydrocarbons (17%; largely *n*-alkanes), and also had acetate esters (3%). Minor amounts of hydrocarbons were present in the other species but not acetate esters. The male adult giant whitefly, *Aleurodicus dugesii*, also had the 3 major lipid classes of alcohols, aldehydes and wax esters, but had only minor amounts of hydrocarbons (largely *n*- alkanes). It was similar to *A. singularis* in that it also had a significant amount of acetate esters (14%).

The waxy particles, which give whiteflies and their surrounding surfaces a white appearance, were composed of alcohols and aldehydes. Each species had a major alcohol and aldehyde, which was 30, 32 or 34 carbons depending on the species. In *A. singularis* it was 32 carbons. Wax esters, hydrocarbons, and acetate esters, if present, were components of the cuticular surface lipids. The wax esters were the major components and ranged in chain length from about C28 to C60 depending on the species. In all species except *A. dugesii*, the major wax esters occurred with an even number of carbons between C40 to C46. In *A. dugesii* the 2 major wax esters were C46 and C60; in both *Bemisia* species, for example, they were C44 and C46.

The adult female giant whitefly has the same lipid classes as the male, but differs in that she deposits a waxy trail in which her eggs are oviposited. This waxy material is formed by posterior wax glands and differs in structure and in composition from the waxy particles produced by the anterior wax glands. The anterior and posterior wax glands of *Bemisia* and *A. dugesii* were characterized by electron microscopy.

*A. singularis* exuviae had no dominant aldehyde (C26-C34) but the major alcohol was C26. No dominant wax ester was present in exuviae but there was a significant amount of unsaturated wax esters containing the C18:1 fatty acid. The major fatty acids in the wax esters were C16 and C18 compared to comparable levels of even numbered fatty acids, C16-C24, in adults. The alcohols of the exuviae wax esters ranged from C26-C32 with no dominant component compared to the adult wax esters which contained C22>C26>C34.

**Investigator's Name(s)**: Steven E. Naranjo and Thomas J. Henneberry

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**Research & Implementation Area**: Section A: Biology, Ecology and Population Dynamics

**Dates Covered By The Report**: April 1995 - October 1997

**Spatial Distribution of Cotton Lint Stickiness and Preliminary Field Sampling Methods for Estimating Stickiness**

Cotton stickiness, due primarily to *Bemisia,* has become a limiting factor in cotton production in many countries, and may presently be considered by the cotton industry as the most serious factor affecting cotton quality. Enzyme-based technologies for ameliorating lint stickiness at either the pre-harvest or post-harvest stage are being developed. To most efficiently deploy these systems it will be necessary to determine whether a field is in need of remedial treatment for stickiness. Research was conducted in 1995-1997 in central AZ and Imperial Valley, CA to examine the distribution of sticky cotton lint, optimize the sample unit size, and determine the number of samples needed for the precise estimation of lint stickiness.

**1995:** Samples were collected on 1-4 dates at each of 5 field sites in Maricopa and Phoenix, AZ beginning about 2 weeks after the first appearance of open bolls. Experimental sample units consisted of all open bolls on 1, 2, 5, 10, 20 or 30 consecutive plants. All six sample units were collected at each of five locations within each field along a diagonal transect. The time necessary to collect each sample was recorded. An aliquot was assayed twice for stickiness using the manual thermodetector. There was no statistical difference in mean estimates of stickiness (thermodetector spots) among the six sample units. Typically, standard deviations were equal to or less than the mean for all sample units indicating a random or Poisson sampling distribution. This pattern differs markedly from the highly clumped sampling distribution of *Bemisia.* Relative net precision (a measure of the ratio between precision and cost) declined dramatically with increasing size of the sample unit from 1 to 30 plants. The 1-plant sample was the most cost-efficient.

**1996:** In 1996 we compared five smaller sample units at fields in Maricopa, AZ and Brawley, CA. Sample units consisted of all open bolls on 1 or 2 consecutive plants, or 5, 10 or 20 open bolls collected along an individual row. These three latter sample units consisted of bolls collected from all vertical strata on the plant. On two sample dates in Maricopa and one date in Brawley all five sample units were collected at each of ten locations within each field along a diagonal transect. The time necessary to collect each sample unit was recorded. Again aliquots were assayed twice for stickiness using the thermodetector method. All samples collected in 1996 were sent to Cotton Incorporated for assay using the automated high-speed thermodetector. Assays are incomplete and most analyses are pending. Lint from approximately one-third of all samples were sent to two additional laboratories for assay using the manual thermodetector. Partitioning of variance components indicated that the majority of variability was associated with assays done by different laboratories, with relatively little variation due to replicate assays at each laboratory or sample-to-sample differences in the field.

**1997:** Samples were collected on one date at three sites in Maricopa, AZ and Holtville, CA Sample units consisted of all open bolls on 1 plant, and 20 or 50 open bolls. All sample units were collected at 8-10 sites per field. Additional sample units were created by combining these primary units after ginning. Five, 10 and 20-plant sample units were formed from 1-plant units and 40, 80, 100 and 200-open boll samples were formed from 20 and 50-boll units. An aliquot from each sample was assayed twice (blindly) for stickiness using the manual thermodetector. There were no significant differences in mean estimates of stickiness among the ten different sample units. Results again indicated that lint stickiness is randomly distributed in the field. Partitioning of variance components indicated that the majority of variability was associated with replicate assays of the same aliquot. Thus, given a finite amount of time to complete sampling, relatively more time should be spent on replicate assays than on collection of additional field samples. The optimal number of replicate samples to perform in the laboratory will depend on the ratio of field to laboratory costs. With the manual thermodetector, results indicate that a minimum of two assays should be completed on each sample. As processing speed increases with the automated system this optimal number may be even higher. Relative net precision was highest for 1-plant and 40-boll sample units. Preliminary sampling plans have been developed for the 1-plant sample unit. Results suggest that high precision (SE/mean ratio = 0.10) in stickiness estimates may be achieved with less than 25 sample units. Lower precision (e.g. 0.20) may be achieved with $\leq$ 5 sample units.

**Investigator's Name(s)**: Maria Regina Vilarinho de Oliveira

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**Research & Implementation Area**: Section A: Biology, Ecology, and Population Dynamics

**Dates Covered By The Report**: 1992 to 1997

## Impact of *Bemisia argentifolii* Bellows & Perring in Brazil

*Bemisia tabaci* was first described in Brazil in 1928 and until 1991 it was considered an occasional pest. It was a problem as a vector of geminivirus in crops such as bean, soybean, cotton, and tomato. Symptoms of silvering squash leaves, explosion of whitefly population and an increase in sooty mould, never seen before in Brazil was detected approximately in 1991, in the southeast region (São Paulo State). It was observed that the pest also attacked some new host plants, such as, weeds, broccoli, squash, cabbage, ornamentals, among others. Isoenzymes and molecular analysis showed that biotype B of *B. tabaci* also known as *B. argentifolii* has entered into the country probably through ornamentals (chrysanthemum and poinsettia). The results also showed that biotype A is disappearing rapidly from the regions where it was commonly found. *B. argentifolii* has spread to almost all regions attacking a variety of crops, such as, melon, watermelon, tomato, cotton, cabbage, soybean, bean, grape among others. The economic losses vary from 30 to 100% in all crops attacked, by decreasing the production and also by vectoring geminivirus. At the moment there are two main lines of research going on presently: chemical and biological control. *Encarsia formosa* is the agent being studied. Prospection of natural enemies, parasitoids and fungi, are being realized in the northeast and southeast regions. Chemicals and soap solutions are also being tested in tomato and watermelon crops. A National Control Programme for the *B. argentifolii* is under elaboration.

**Investigator's Name(s):** Thomas M. Perring and Charles A. Farrar

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**Research & Implementation Area:** Section A: Biology, Ecology, and Population Dynamics.

**Dates Covered by the Report:** January 1, 1997- December 31, 1997.

## Sampling protocol for silverleaf whitefly on tomato

First year research showed that trap catches of adult whiteflies were highly variable, and poorly correlated with numbers of adults and eggs counted on tomato plants. However, the relationship between leaf turn counts of adults and numbers of eggs was strong ($r^2$=0.94 and 0.99, depending on how many leaves were used to estimate the adult density). In the second year, egg counts again were shown to correlate closely with the adult counts ($r^2$ = 0.823).

Regression analyses of the nymph and adult data showed a wide range of regression coefficients depending on which week the nymph counts were regressed on the adult counts. While the most significant regression coefficients were produced when nymphs were regressed on adult leaf turn counts taken 5 weeks earlier in the interior of the field, significant relationships were present for leaves aged 3-6. This suggested that adults counted using leaf turns were a good predictor of the numbers of nymphs that developed subsequently on the leaves. Since the nymphs are the whitefly life stage responsible for causing tomato irregular ripening, the demonstration of this relationship is crucial for implementing a sampling program. To relate these data to the threshold work of Dr. Charlie Summers (who sampled nymphs on node 4 from the terminal), the node position of 3, 4 and 5 week old foliage was determined for the season. This analysis showed that node 4 was well within the range of variation for 3 week old foliage for the first 7 weeks of our study. Later in the season, the determinate nature of the plants stopped adding nodes to the branches, thus the mean node number decreased. Using linear regression for three week old foliage, nymphal densities were related to adult densities by the formula:

$$\text{Estimated number of nymphs} = 0.922\ (\text{Adults}) - 16.719$$
$$(r^2 = 0.635,\ P = 0.0001)$$

Based on adult leaf turn counts, this equation explains a significant amount (64%) of the variation in the number of nymphs on the 3 week old foliage.

**Investigator's Name(s):** G.R. Wolfe, D.L. Hendrix & M.E. Salvucci.

**Affiliation & Location:** USDA, ARS, WCRL, Phoenix AZ.

**Research & Implementation Area:** Section A. Biology, Ecology, and Population Dynamics.

**Dates Covered by the Report:** January 1997 – December 1997.

## Sorbitol Metabolism in *Bemisia argentifolii*: Cloning of the NADPH-Dependent Ketose Reductase

Accumulation of polyols in insects is well known as a cold-hardening response related to overwintering or to protection against cold shock. The silverleaf whitefly (Bellows and Perring) is a major insect pest in tropical and subtropical regions where heat stress and desiccation pose formidable threats to survival. We found that sorbitol levels increased ten-fold when whiteflies were exposed to elevated temperatures. Sorbitol levels rose from 0.16 nmol whitefly$^{-1}$ at 25°C to 1.59 nmol whitefly$^{-1}$ at 42°C. Sorbitol levels fluctuated diurnally under glasshouse and field conditions increasing ten-fold from morning to early afternoon. Feeding experiments on artificial diets showed that both temperature and dietary sucrose concentration were key factors influencing sorbitol accumulation. Cell free extracts prepared from adult whiteflies catalyzed NADPH-dependent fructose reduction, but were unable to reduce glucose with either NADPH or NADH. Sorbitol synthesis in the whitefly was catalyzed by a novel NADPH-dependent ketose reductase. We cloned and sequenced a cDNA that encoded the NADPH-KR/SDH to determine the primary structure of this unusual enzyme. The cDNA encoded a protein of 352 amino acids with a calculated molecular mass of 38.2 kDa. The deduced amino acid sequence of the cDNA shared 60 and 41% identity with sheep and silkworm $NAD^+$-dependent sorbitol dehydrogenases, respectively. We propose that the ketose reductase-mediated sorbitol accumulation is a mechanism for thermoprotection and osmoregulation in the silverleaf whitefly, allowing the insect to thrive in environments conducive to thermal and osmotic stress.

## Research Summary

Section A: Biology, Ecology and Population Dynamics
Compiled by S. E. Naranjo

### *Basic Biology and Taxonomy*

Based on submitted abstracts and recent publications, progress was made in all areas related to Section A objectives 6-10.

Electrophoretic and molecular analyses have documented the presence and extent of *B. argentifolii* (or *B. tabaci*, Biotype B) in Australia and Brazil. *B. argentifolii* is now widely distributed in New South Wales, Queensland, and the Northern Territory and has also been found in Tasmania. *B. argentifolii* is also widely distributed in many states in Brazil where it appears to be displacing *B. tabaci* Biotype A and is having a large impact on agricultural production through direct feeding and geminivirus transmission. Field surveys in Australia report the existence of heterozygotes between *B. argentifolii* and the extant Australian type *of B. tabaci* which corroborates previous laboratory studies that showed interbreeding between B and non-B types.

Comparative morphological analyses were completed on *Bemisia* pupae from around the world. Researchers from Arizona, California, Texas and the U.K. examined a number of characters, including anterior submarginal setae, anterior and posterior wax fringes, dorsal setae, posterior submarginal setae, caudal setae and tracheal folds. They found that several of these characters were highly variable among populations and concluded that pupal morphology could not be used as the sole criteria for classifying individuals within the *Bemisia* complex. The surface lipid composition of several *Aleyrodes* spp. were characterized and compared with the known composition of those of *B. tabaci* and *B. argentifolii* by researchers in North Dakota, California and Israel.

Researchers in Arizona have documented the presence of the polyol sorbitol in *B. argentifolii*. Higher levels of sorbitol were associated with increasing levels of sucrose and in particular with elevated ambient temperatures. In insects, polyols are known to protect enzymes against heat denaturation, and they suggest that sorbitol may function as a thermoprotectant in whiteflies enabling them to thrive in desert environments. Further studies showed that the pathway of sorbitol synthesis in *B. argentifolii* is unique and involves the use of a NADPH-dependent ketose reductase. The gene that encodes for this enzyme has been cloned and may offer and avenue to develop transgenic plants which disrupt this unique synthetic pathway.

The effects of antibiotics on the biology of *B. argentifolii* were studied by Arizona and California researchers. Antibiotics that interfere with bacterial protein synthesis affected growth and development while those that primarily attack bacterial cell walls or cell membranes had no effect on growth and development. None of the antibiotics affected oviposition rates or sex ratio. Results have important implications for the use of antibiotics to disrupt the function of whitefly endosymbionts as a potential control method.

Researchers in Arizona have developed an artificial diet and feeding system for rearing immatures of *B. argentifolii*. They compared a number of diet, including diets using 30% sucrose mixed with various insect culture media, diets including amino acids found in yeast extract and others containing various yeast preparations. The best diet was one containing 30% sucrose and 5% yeast extract. It allowed development to the fourth instar but did not produce adults. Rates of development of individual instars were comparable to those estimated on various host plants. The feeding system has proven to be a useful bioassay for examining diet components and for studies of primary metabolism based on defined diets.

Movement of adult *B. argentifolii* was studied in relation to light intensity in California. Results suggest that movement is minimal when light intensity was less than 2 lux.

### *Ecology and Population Dynamics*

Based on submitted abstracts and recent publications, progress was made in all areas related to Section A objectives 1-5.

Arizona researchers completed partial life tables for immatures of *B. argentifolii* on cotton in relation to different management strategies. Predation and dislodgment accounted for nearly all mortality in untreated fields and survivorship from egg to adult ranged from 1-8.5% over 4 generations. In treated plots, predation, dislodgment and insecticides accounted for nearly all mortality and survivorship ranged from 0-7.5% over 2 generations. Parasitism was very low in all fields and never exceeded 2.5% on a generational basis. Results showed that predation was generally higher in untreated fields or in those treated with insect growth regulators compared with fields treated with conventional insecticides. This suggests that use of insect growth regulators may help conserve natural enemies. Researchers in Israel examined the dynamics of *B. argentifolii* and it's parasitoids on lantana, one of the few perennial hosts of whitefly in this country. Results indicated that whitefly populations remain low on this host despite intentional introductions of *B. argentifolii* several times during the study. Rates of parasitism

fluctuated widely and probably contributed to control on this wild host plant.

*B. argentifolii* and natural enemy populations were monitored in commercial cotton fields by California researchers in the Imperial Valley. Analyses suggested that whitefly densities declined in relation to increased insecticide use and field size and increased in relation to proximity to spring melon fields, and later planting dates. Natural enemy and whitefly populations appeared to cycle in unison. Researchers in California also monitored *B. argentifolii* in multiple crops in the San Joaquin Valley as part of an areawide management trial for cotton. Arizona researchers monitored whiteflies and natural enemies in cotton as part of a continuing study to evaluate and demonstrate strategies for whitefly management. Overall rates of parasitism of 4th instars were highest in fields treated with the insect growth regulator pyriproxyfen, but never exceeded 30% in any field. Predators were negatively affected by the use of conventional insecticides, but were generally unaffected in fields treated with insect growth regulators. Texas researchers completed surveys of *B. argentifolii* and parasitoid abundance within a number of affected crops in the Lower Rio Grande Valley. These studies helped identify farming practices, cropping patterns and other agronomic factors that need to be considered in the potential development of areawide management programs. Surveys in Brazil indicate that *B. argentifolii* is spreading rapidly throughout the country and is affecting a number of crop, including melon, watermelon, squash, tomato, cotton, cabbage, soybean, bean, grapes, broccoli and some ornamentals.

Arizona researchers are studying the temporal distribution of honeydew deposition by *B. argentifolii* in cotton and the relationship between lint stickiness and whitefly abundance. Most honeydew accumulation on open cotton bolls occurs from mid-August onward. Lint stickiness did not exceed levels of concern until whitefly populations reached 7-12 adults per leaf or 1.7-2.8 nymphs per $cm^2$ during the period when mature cotton bolls were present. Further studies indicate that adult whiteflies produce more trehalulose than nymphs, but nymphs produce more melezitose than adults. Both sugars are highly correlated with lint stickiness.

Progress has been made in the development of sampling plans for *B. argentifolii* on tomato in California. Researchers have examined within plant distributions of immatures and have developed preliminary relationships between pest density and the occurrence of tomato irregular-ripening. The within-field distribution of sticky cotton was studied and characterized in Arizona. Unlike the highly aggregated distribution of *B. argentifolii*, sticky cotton is randomly distributed in cotton fields. Researchers have compared the efficiency of a number of absolute and relative sample units for estimating lint-stickiness and have examined between-laboratory and between-assay variability in stickiness determinations by thermodetector. A preliminary sampling plan for estimating pre-harvest lint stickiness has been developed. Work continues on evaluation of a reusable trap for capturing adult whiteflies. Researchers in Arizona and California examined capture in relation to trap color and height of trap placement within the crop canopy in cotton and several other affected crops. Results indicate that lime green is a preferred color and traps placed lower in the canopy tend to capture more whiteflies.

Researchers in Arizona studied the aerial distribution of *B. argentifolii* from cantaloupe fields using traps placed at varying heights and distances from the source field. Results revealed a negative exponential relationship between capture and height and a slightly weaker negative relationship between capture and distance. Examination of egg-loads of captured adults also suggests a negative relationship between flight distance and oogenesis. Preliminary studies on dispersal of exotic *Eretmocerus* from The United Arab Emirates were conducted in Arizona on cotton and cantaloupe.

Work continues on the development of large-scale temporal and spatial models of *B. argentifolii* dynamics in regional cropping systems. Researchers recently used such a model to examine the dynamics of whiteflies in a organic cropping system in south Florida. Simulations provided insight into the comparative importance of planting dates and spatial heterogeneity in crops on whitefly dynamics. Work also continued on a temperature-dependent, site-specific population dynamics model of *B. argentifolii*. Simulations have examined the comparative impacts of two parasitoid species and the potential impact of whitefly immigration on augmentative biological control. The model simulates whitefly dynamics in cotton and cantaloupe and is being expanded to include other affected crops.

**Table A. Biology, Ecology, and Population Dynamics.**

| Research Approaches | Year 1 Goals Statement | Progress Achieved Yes | Progress Achieved No | Significance |
|---|---|---|---|---|
| **Determine life cycle vulnerabilities (life tables)[a], population development and natural mortality factors, natural enemies on major crops, urban plantings, weeds and predict overwintering potential.** | Whitefly and natural enemy sampling in cultivated crops, urban planting and weed hosts. | X | | Partial life table analyses have been completed for *B. argentifolii* on cotton in Arizona. Natural forces, including predation and dislodgment are major mortality factors; parasitism was a minor source of mortality. Survivorship from egg to adult ranged from 0-8.5% over 4 generations in sprayed and unsprayed fields. Studies on wild host crops in Israel indicate that parasitoids may contribute to low levels of whitefly on lantana. Whitefly and natural enemy populations were monitored in cropping systems in the Imperial and San Joaquin Valleys of California, Maricopa, Arizona and the Rio Grande Valley of Texas. The spread of *B. argentifolii* is being documented in Brazil. Life table studies provide valuable quantitative information on sources of whitefly mortality; surveys define the temporal and spatial dynamics of pest and natural enemy populations. This information is critical in developing and refining more biologically-based management systems. |
| **Develop sampling methodology, action and[b,c] economic thresholds for all major crops. Sampling methods and thresholds modified in light of natural enemy levels and existing management strategies.** | Initiate whitefly to identify spatial and temporal distributions in major cultivated crops. | X | | Relationships between whitefly density and the occurrence of tomato irregular-ripening as well as preliminary sampling plans for whitefly on tomato have been developed. Evaluations of a reusable trap for surveying adult whiteflies in various crops are continuing. Studies of the effects of various insecticides on whitefly natural enemies are ongoing. Sampling plans and action thresholds are still needed for a number of affected crops. |

**Table A. Biology, Ecology, and Population Dynamics. (Continued)**

| Research Approaches | Year 1 Goals Statement | Progress Achieved Yes | No | Significance |
|---|---|---|---|---|
| **Develop population models to describe and predict whitefly population growth and spatial and temporal distribution. Develop simple day-degree sub-models for estimating phenology and temporal patterns of whitefly, natural enemies and host crops.** | Summarize whitefly biology, ecology and plant phenology to identify whitefly host plant interfaces. | X | | Development of large-scale temporal and spatial models and temperature-dependent, site-specific population dynamics models continues. Such models have the potential to encapsulate our current knowledge and provide a framework for developing more efficient management systems. However, considerable biological and ecological detail, as well as information on various aspects of pest management is available and needs to be integrated into these models to make them most useful as exploratory tools. |
| **Develop sampling methods for quality of cotton lint, vegetables and other commodities.** | Initiate sampling of seed cotton in the field during the season, at harvest, after picking, moduling and ginning. | X | | Research has characterized the temporal distribution of honeydew deposition by *B. argentifolii* in cotton, improved our understanding of the relationship between lint stickiness and whitefly abundance and compared the production of trehalulose and melezitose between nymphs and adults. Studies reveal that cotton lint stickiness is randomly distributed in cotton fields. Preliminary sampling plans have been developed for estimating pre-harvest cotton lint stickiness. Stickiness constitutes one of the most important problems currently facing the cotton industry. |
| **Quantify whitefly and natural enemy dispersals and contribution to population dynamics.** | Review and analyze existing knowledge of whitefly dispersal. | X | | Studies have characterized the aerial distribution of whiteflies dispersing from cantaloupe fields and have examined the trade-offs between oogenesis and flight activity. Studies on whitefly parasitoid dispersal are ongoing. Understanding and predicting the timing and extent of the movement of whiteflies and their natural enemies is an important component in developing areawide management systems. |

**Table A. Biology, Ecology, and Population Dynamics. (Continued)**

| Research Approaches | Year 1 Goals Statement | Progress Achieved Yes | Progress Achieved No | Significance |
|---|---|---|---|---|
| **Define mating behavior, reproductive isolation, species, biotypes.** | Initiate studies on mating, oviposition and other behavior. | X | | Surveys worldwide continue to document the spread of *B. argentifolii*. Electorphoretic analyses demonstrate the presence and extent of this pest in throughout Australia and Brazil. *B. argentifolii* appears to be displacing *B. tabaci* Biotype A in Brazil and is having a large impact on agricultural production through direct feeding and geminivirus transmission. Reports of heterozygotes between *B. argentifolii* and the extant Australian type *of B. tabaci* corroborates previous laboratory and highlight the taxonomic challenges within the *Bemisia* species complex. |
| **Validate *Bemisia* taxa morphology, genetic, biochemical, and biology characteristics.** | Continue examination of *Bemisia* sp. for distinct morphological character differences. | X | | Comparative morphological analyses have been completed on *Bemisia* pupae from around the world. Several of these characters are highly variable among populations suggesting that pupal morphology should not represent the sole criteria for classifying individuals within the *Bemisia* species complex. |
| **Define role of endosymbionts in metabolism, host adaptation, nutrition and survival.** | Identify endosymbionts in whitefly. | X | | The effects of antibiotics on the biology of *B. argentifolii* have been examined. Several antibiotics that interfere with bacterial protein synthesis affected growth and development of immatures, but none affected oviposition rates or sex ratio. Results have important implications for the use of antibiotics to disrupt the function of whitefly endosymbionts and other associated microbes as potential control methods. |
| **Characterize nutrient uptake and metabolism** | Determine the process of uptake and metabolism of carbohydrates, amino acids and other nutrients. | X | | High levels of a polyol, sorbitol, were associated with elevated ambient temperatures. Sorbitol may function as a thermoprotectant in whiteflies that enables them to thrive in desert environments. The pathway of sorbitol synthesis and degradation in *B. argentifolii* is unique and may offer and avenue to develop transgenic plants which could disrupt sorbitol synthesis and compromise the whiteflies ability to deal with heat stress. |

**Table A. Biology, Ecology, and Population Dynamics. (Continued)**

| Research Approaches | Year 1 Goals Statement | Progress Achieved Yes | Progress Achieved No | Significance |
|---|---|---|---|---|
| **Develop whitefly artificial diets and natural enemy mass-rearing.** | Identify whitefly nutritional components in plant tissue. | X | | An artificial diet and feeding system for rearing immatures of *B. argentifolii* has been developed. Rates of development of individual instars were comparable to those estimated on various host plants. The feeding system has proven to be a useful bioassays for examining diet components and for studies of primary metabolism based on defined diets, and has the potential to provide a means of mass rearing whitefly parasitoids. |

[a] Natural enemy research complements from Section D, see Table D.
[b] Action and economic thresholds also apply in Section C, see Table C.
[c] Sampling technology applicable to all other sections, see Tables B to F.

**Reports of Research Progress**
**Section B: Viruses, Epidemiology, and Virus-Vector Interactions**
Co-Chairs: Robin N. Huettel and Doug Maxwell

**Investigator's Names**: M. J. Davis, Z. Ying and R.T. McMillan, Jr.

**Affiliation & Location**: University of Florida, TREC, Homestead, FL.

**Research & Implementation Area**: Section B : Viruses, Epidemiology, and Virus-Vector Interactions.

**Dates Covered By The Report**: 1997-1998.

## Occurrence of Tomato yellow leaf curl geminivirus in the United States

Tomato yellow leaf curl geminivirus (TLCV) was identified in the United States for the first time in late July 1997 in a field planting at a commercial breeding facility in Florida. Shortly thereafter, infected tomato plants were also found in several retail garden outlets in Florida (personal communication J. Polston) . The source of these plants was traced back to two commercial nurseries near Homestead in south Florida that had shipped tomato plants to retail outlets in Florida and other states and out of the country. Subsequently, infected tomatoes from retail garden outlets have been found in Virginia (confirmed by laboratory tests) and possibly other locations in the southern United States supporting the possibility that TYLCV will become a regional problem.

Due, apparently, to the introduction and spread of the silverleaf whitefly, there has been a recent emergence of seventeen whitefly-transmitted geminiviruses in tomato in the Western Hemisphere. Of these, only tomato mottle virus was present in Florida before TYLC. We used polymerase chain reaction (PCR) and DNA sequence analyses to confirmed the recent introduction of TYLCV into Florida. Degenerate primers for geminiviruses were used to amplify a fragment of the viral genome containing part of the coat protein gene. The partial gene sequence had greater than 98% homology with that of an Israel strain of the TYLCV. These results suggest that the virus is an Eastern Mediterranean strain and possibly the same strain previously introduced into the Dominican Republic from Israel in 1991 and subsequently found in Jamaica and Cuba. We have designed non-degenerate primers for PCR detection of TYLCV based on our DNA sequence data for the virus. Detection of TYLCV in tomato plants with these primers has been 10-100 times more sensitive than with the degenerate primers, which even with the degeneracy have mismatched bases.

Tomatoes are a winter crop in south Florida, and TYLCV was detected in October, 1997, in newly established commercial plantings. Tomatoes are still being planted in south Florida at the present time. The incidence of TYLCV-infected plants initially appeared to be due mostly to primary spread into the fields. Sources of inoculum are presumed to be weeds outside of the tomato fields. Whitefly population densities have been generally low, and even less in tomatoes due to the extensive application of the systemic insecticide, imidacloprid, to transplants. However, the occurrence and incidence of TYLCV in cultivated tomatoes have steadily increased during the growing season. Secondary spread within fields has become more prevalent and whitefly population densities are on the increase. TYLCV appears to be firmly established in Florida, and will likely become a major problem in the region in years to come.

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**Research & Implementation Area:** Section B: Viruses, Epidemiology, and Virus-Vector Interactions.
**Dates Covered by the Report:** 1997.

## Feeding Behavior May Explain Why Nonpersistent Viruses Are Transmitted Primarily By Aphids, Not Whiteflies

Whiteflies are one of the major groups of insect vectors of plant viruses. Nonetheless, the viruses transmitted by whiteflies are not equally distributed among the four major classifications of insect transmitted plant viruses: the persistent-propagative, persistent-circulative, semipersistent, and nonpersistent viruses. The great majority of plant viruses transmitted by whiteflies (>90%) are geminiviruses which are transmitted in a persistent, circulative manner. The largest group of plant viruses transmitted by insects, the nonpersistent viruses, are transmitted almost exclusively by aphids. Of the approximately 211 known nonpersistent viruses, 208 are transmitted by aphids and only 3 are transmitted by whiteflies. This suggests the existence of one or more important biological differences between aphids and whiteflies that affect their propensity to transmit nonpersistent viruses. Recent studies in other laboratories using the electronic monitoring technique have determined the specific behavioral event during stylet penetration by aphids where nonpersistent viruses are transmitted to plants. Electronic monitoring studies on stylet penetration by whiteflies (*Bemisia argentifolii* Bellows & Perring and *Parabemisia myricae* [Kuwana]) in our laboratory have revealed major differences between whiteflies and aphids in respect to the stylet penetration behavior recently shown to be responsible for nonpersistent virus transmission by aphids. These differences are summarized below.

Although stylet penetration by most aphids species (including the most important vector species) follows a predominantly intercellular pathway, aphids make frequent brief (generally <10 s) intracellular punctures into cells that they pass along the intercellular pathway. Generally, almost every cell that is passed along the pathway to the sieve elements (the target feeding site) is briefly penetrated one or more times. Even short duration probes (<1 min) by aphids usually include one or more brief intracellular punctures. Recent studies in other laboratories have shown that these brief intracellular punctures are the specific behavioral event where nonpersistent viruses are transmitted (acquired and inoculated) by aphids. Details of the electronic monitoring waveforms recorded during these brief intracellular punctures indicate that three discrete sequential behaviors occur once the stylet tips penetrate the cell membrane. The third behavior in the sequence is a brief ingestion period and is where the viruses are acquired. Inoculation occurs predominantly during the first behavior in the sequence. Whitefly stylet penetration behavior is similar in many respects to stylet penetration by aphids. Whitefly stylets also follow a predominantly intercellular pathway, and the target feeding site is the phloem sieve element. However, the occurrence of brief intracellular punctures during the stylet pathway differs between whiteflies and aphids in two major respects. While brief intracellular punctures occur frequently during stylet penetration by aphids, and occur as early as 10 s from the beginning of the probe, brief intracellular punctures by whiteflies are much less frequent, and occur only late in the probe. For example, the average times to the first brief intracellular puncture by *Bemisia argentifolii* feeding on lima bean, broccoli, corn, and sugar beet are 18, 34, 53, and 20 min, respectively. Furthermore, short duration probes (< 1 min) where there is one or more intracellular puncture are the most likely probes to result in transmission of nonpersistent viruses by aphids. While whiteflies also frequently make short duration probes, intracellular punctures virtually never occur during these short duration probes by whiteflies. Thus, given the critical importance of intracellular punctures during short duration probes in nonpersistent virus transmission by aphids, the virtual absence of intracellular punctures during short duration probes by whiteflies is likely to be a major reason why whiteflies are not efficient vectors of nonpersistent viruses. Additionally, while electronic monitoring waveforms indicate that three discrete sequential behaviors occur once aphid stylet tips penetrate the cell membrane, and these different behaviors appear to play specific roles during inoculation and acquisition of nonpersistent viruses, electronic monitoring waveforms of whiteflies do not detect a sequence of three separate behaviors after the stylet tips penetrate the cell membrane. In whiteflies, the electronic monitoring waveforms recorded during intracellular stylet punctures suggest the occurrence of a single behavior during the time that the stylet tips in an intracellular position. Exactly what this behavior is and how it may influence transmission of plant viruses will require further study for elucidation.

**Research Summary**
**Section B. Viruses, Epidemiology, and Virus Vector Interactions.**
Compiled by Robin N. Huettel

**B.1. Identification and characterization of new or emerging whitefly-transmitted viruses and strains.**

The family Geminiviridae is characterized based on twinned icosahedral virions and single-stranded DNA genomes. There are three subgroups based on the vectors. The first and second subgroups are leafhopper transmitted and infect monocot and dicot plants, respectively. The third subgroup is transmitted only by whiteflies. Most of the whitefly transmitted members have a bipartite genome composed of two equally sized genomic components, designated A and B. However, there is a monopartite virus, tomato yellow leaf curl virus (TYLCV) within the whitefly transmitted geminiviruses.. There are about 17 geminiviruses reported in the Americas that infect tomato alone. This group of virus is considered the most important emerging group of viruses known at this time. Even though these viruses tend to have a narrow host range, they appear to readily undergo 'local evolution' with different geminiviruses causing the same disease.

Various molecular techniques have been developed to identify geminiviruses in plants as well as to characterize the viruses themselves. In plants, polyclonal and monoclonal antibodies against the coat protein have been developed to detect and distinguish the viruses and there are some commercial sources of antibodies available. Other assays that are use for virus detection include cloned DNA of the virus and dot spot and squash blot hybridization. Polymerase chain amplification reaction (PCR) is useful in detection of virus in small amounts of tissue and it is extremely sensitive. The viruses themselves are identified mostly by their DNA sequences. The common region or intergenic region, the coat protein and the replicase-associated protein are the regions of the genome commonly used in taxonomic studies. These approaches were successful in identifying the TYLCV from the Dominican Republic and finding that it had 98% homology to the Eastern Mediterranean TYLCV.

**B.2. Molecular epidemiology: Identification of economic viruses, plants and reservoirs, and determination of geographic distribution of viruses.**

Many of the geminiviruses have been identified by molecular techniques using sequence data when available. In Florida, PCR and DNA sequence analysis was used to confirm the recent introduction of TYLCV . The Florida population has greater than 98% homology to the Dominican Republic strain and to the strains found in Jamaica and Cuba. All were similar to the Eastern Mediterranean strain. The TYLCV has been found in infected tomatoes from Virginia and possibility other southern states. Detection of TYLCV using designed non-degenerate primers for PCR detection has been 1- to-100 times more sensitive than with degenerate primers. Weeds are being investigated as outside sources of infection. In the Dominican Republic, weeds were found not to be the primary source of infection but a few weed species were found to have incidences of infection. Such infected weeds could allow for the virus to persist throughout the host-free period.

**B.3. Virus-vector interactions, factors affecting virus transmission, and basis for virus-vector specificity: determination of endosymbiont involvement in whitefly mediated transmission.**

Differences in feeding behaviors of aphids and whiteflies indicated that whiteflies do not make cellular punctures during the early phases of stylet probing. It appeared these punctures only occurred later in the feeding as the stylets reached the vascular tissues. The importance of considering virus-vector interactions was discussed in other sections, especially in resistance breeding for whitefly. It was pointed out that in some cases, whitefly resistant varieties may be more prone to virus infection (See Section E). There were no update on endosymbiont involvement in whitefly mediated transmission.

**B.4. Strategies to reduce virus spread by management of cropping systems, reduced transmission frequencies, and other potentially effective approaches.**

The use of whitefly host-free periods in the Dominican Republic where whitefly hosts such as tomato, beans, melons, and peppers were not grown for a 3 month period dramatically reduced the incidence of TYLCV. In tomato production in Florida, management practices involve good field sanitation, tomato-free periods between production and the use of chemical control to manage whiteflies. The use of commercial transplants produced in areas where the chance of virus infection is reduced is also being evaluated. In whitefly reduction studies using biological control based IPM, there was a 10% reduction in geminiviruses in squash (See Table D)

**B.5. Control of virus diseases; development of virus resistant germplasm through conventional and engineered/molecular approaches. Define prospective strategies for selecting candidate viruses, identifying specific virus diseases to target, and prioritize specific crops and cultivars for protection approaches.**

Geminiviruses have been hard to tag with conventional indicator genes due to size constraints. Recently, the autofluorescent GFP gene (green fluorescent jellyfish protein gene) was successfully used to tag the bean dwarf mosaic virus (BDMV). By using autofluorescence and confocal microscopy, the virus movement cell to cell from the cortical cells to the phloem cells could be monitored. In susceptible varieties, the virus was observed to move down the root tip and eventually out to the shoot apex. There also appears to be cell to cell movement that is not phloem limited. In the resistant bean variety, "Pinto" the virus still replicated and moved but within 48 hours necrosis was observed in the vascular areas with little long distance movement through the phloem. There was a collapse and death of cells at the infection site and the virus never appeared in the shoot apex as in a susceptible variety. These studies will help in determining resistance to virus in plants as well as the possibility of utilizing the resistance gene(s) in "pinto" through conventional breeding. If the resistant gene(s) are identified then they might be candidates for engineered resistance in other plants. Three rust and bean golden mosaic geminivirus snap bean lines were released in Florida. By using PCR, a polymorphic DNA marker was developed and used to identify plants containing the recessive genes in either susceptible or resistant conditions. Cotton cultivars and seed lines were screen for silverleaf whitefly and cotton leaf crumple virus symptoms with some resistance to the virus found in two lines (see Section E).

**B.6. Pursue specific genetic and biological basis for variability in whitefly biotypes, strains, and species: determine impact of different genotypes/phenotypes on whitefly-mediated transmission and on the epidemiology of virus disease**

There were no updates in area.

**Table B. Viruses, Epidemiology and Virus Vector Interactions.**

| Research Approaches | Year 1 Goals Statement | Progress Achieved Yes | Progress Achieved No | Significance |
|---|---|---|---|---|
| **Identification and characterization of new or emerging whitefly-transmitted viruses and strains.** | Monitor crops for presence of whitefly-transmitted diseases, and determine relative disease incidence. Begin virus identification and strain differentiation. | | X | Rapid techniques are available for identification and characterization of geminiviruses through sequencing of PCR-amplified viral DNA fragments. This approach was used to show 98% sequence identity between the tomato yellow leaf curl gemini virus (TYLCV) from the Dominican Republic and an Eastern Mediterranean virus strain indicating that the virus was probably introduced on tomato transplants from the Eastern Mediterranean area The use of such sequences in comparisons of viruses are important in establishing their relatedness and origin. Several other assays are available for rapid detection of geminiviruses such as dot blot and squash blot hybridization analysis. |
| **Molecular epidemiology: identification of economic viruses, host plants, and reservoirs, and determination of geographic distribution of viruses.** | Monitor and identify host plants, virus reservoirs in affected areas. Linkages to diagnostic methods for virus ID and tracking. | | X | The use of squash blot analysis using a TYLCV-specific DNA probe to assess the role of weeds as hosts in the Dominican Republic showed that they were not infected with TYLCV and not significant molecular sources for the virus. TYLCV newly discovered in Florida was also 98% identical to the Dominican Republic strain. Geminiviruses, are known throughout the world and distinct viruses are known to occur in many countries. For instance, tomato mottle virus ToMoV) was first detected in Florida in 1989 and is thought to have originated from that state. |

**Table B. Viruses, Epidemiology and Virus Vector Interactions. (Continued)**

| Research Approaches | Year 1 Goals Statement | Progress Achieved Yes | Progress Achieved No | Significance |
|---|---|---|---|---|
| **Virus-vector interactions, factors affecting virus transmission, and basis for virus-vector specificity; determination of endosymbiont involvement in whitefly-mediated transmission.** | Initiate studies on virus-vector interactions and on basis for the specifcity of whitefly-mediated geminivirus transmission. | | X | Studies on feeding duration and position has demonstrated differences in aphids and whiteflies. These differences may determine why some geminiviruses are transmitted by one group and not the other. The use of the autoflourescent GFP gene, in tracking the virus movement and replication in plants indicated that a cell to cell movement of the virus occurred and the virus was not phloem limited. Understanding the movement of the virus in terms of insect feeding behavior may play a role in developing resistant varieties. |
| **Strategies to reduce virus spread by management of cropping systems, reduced transmission frequencies, and other potentially effective approaches.** | Develop approaches to managing cropping systems to reduce vector densities to decrease transmission frequency and inoculum sources, taking into account weed and crop reservoirs in disease incidence and distribution. | | X | Host-free practices used in the Dominican Republic for TYLCV have been successful in reducing the incidence of this disease. In Florida, management of whiteflies with insecticides, field sanitation, and clean transplants has reduced the incidence of ToMoV. In whitefly reduction studies using biological control based IPM, there was a 10% reduction in geminiviruses in squash (See Table D). |
| **Control of virus diseases: development of virus resistant germplasm through conventional and engineered/molecular approaches. Define prospective strategies for selecting candidate viruses, identifying specific virus diseases to target, and prioritize specific crops and cultivars for protection approaches.** | Define strategies for resistance efforts. Identify target viruses. Identify germplasm with virus resistance. Initiate efforts toward defining prospective engineered resistance strategies. Identify candidate crops and recipient cultivars. | | | Resistance to the geminivirus, bean dwarf mosaic virus (BDMV), was found in □Pinto□ bean variety, Othello. Using the GFP gene as a marker, virus infection in this variety was compared with that in a susceptible variety. In the resistant variety, there was a collapse of tissue at the infection site and continuing necrosis in the vascular areas indicating a hypersensitive reaction to the virus. The gene(s) involved in this response may be a source of resistance to this virus either through conventional breeding efforts or by identifying the gene(s) involved. In cotton, some resistance to the cotton leaf crumple virus was reported (See Table F). |

**Table B. Viruses, Epidemiology and Virus Vector Interactions. (Continued)**

| Research Approaches | Year 1 Goals Statement | Progress Achieved Yes | Progress Achieved No | Significance |
|---|---|---|---|---|
| **Pursue specific genetic and biological basis for variability in whitefly biotypes, strains, and species; determine impact of different genetypes/phenotypes on whitefly-mediated transmission and on the epidemiology of virus diseases.** | Identify differences in species, strains and biotypes with respect to transmission, host range, mating compatabilities, molecular variability, and map the biogeographic distribution of distinct types within the *B. tabaci* species complex. | | | No reports in this area. |

**Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods**
Co-Chairs: Tim Dennehy and Phil Stansly

**Investigator's Name(s)**: D.H. Akey, C.C. Chu, and T.J. Henneberry.

**Affiliation & Location**: USDA-ARS, Western Cotton Research Laboratory, Phoenix, AZ.

**Research & Implementation Area**: Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

**Dates Covered by the Report**: 1997.

## NI-25 (Rhone-Poulenc EXP 80667A) - an Experimental Systemic Insecticide for Silverleaf Whitefly Control on Cotton

At Maricopa, AZ in 1997, foliar applications of NI-25 effectively reduced seasonal average silverleaf whitefly densities on cotton to 4-6 small nymphs and 1-2 large nymphs per $cm^2$ leaf disk compared to 31 and 10 for small and large nymphs, respectively, in untreated plots from July to September 1997. Numbers of applications were 3, 3, and 2 at rates at 0.05, 0.075, and 0.1 lb AI/ac, respectively. The action threshold occurred when 57% of 30 sampled leaves had 3 or more adults per leaf turn for the NI-25 treatments and additional 0.5 to 1.0 large nymphs per 4 $cm^2$ leaf disk was found for the Knack and Applaud treatment. The cotton lint was clean and not sticky in appearance and touch in treated plots. In untreated control plots, cotton lint was highly contaminated with black sooty molds and was sticky.

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**Research & Implementation Area:** Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

**Dates Covered by the Report:** June 1997 - October 1997.

## Use of the Azadirachtin product, Bollwhip®, as a Biorational Agent Against the Silverleaf Whitefly, *Bemisia argentifolii*, in Field Trials in Upland Cotton

Deltapine 5415 was planted and furrow irrigated in plots 192.5 ft. in length and 6 rows across (40 in. rows). Plots were separated by 2 fallow rows and 8 ft. alleys. Bollwhip® was used in a 4.5% formulation at 3 rates: 3, 6, and 9 oz./ac. These treatments were part of a 16-treatment random block design that included a "best agricultural practice regime," a water-treated control, and an adjacent 1-ac block control. Eggs, small nymphs, and large nymphs were sampled from leaves taken from 5 plants per plot, from the fifth main-stem leaf down from the first expanded terminal leaf. Each sample was counted from a 1-in. disk taken between the main leave stem and the next lateral vein. Adults were sampled from 30 leaves/plot, same location using a binomial decision of counting a leaf as positive if 3 or more adults were present. Weekly sweeps were taken in all plots for predators, parasites, and *Lygus* ; these collections and data are still being processed. Applications were made by ground with 3 nozzles/row; 1 overhead, and 2 with swivel nozzles angled upward on drops. Sprays were applied at 80 psi and 30 gal./ac. Bollwhip® was effective at controlling silverleaf whiteflies at all three levels used. The seasonal mean reduction for 8-weekly applications was better than 5-fold less eggs, 4-fold less small nymphs, and 3-fold less large nymphs, than for the block control (all significant at $P<0.0001$, ANOVA). Yield was excellent and large bolls with non-sticky cotton were produced.

**Investigator's Name(s):** D.H. Akey and T.J. Henneberry.

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**Research & Implementation Area:** Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

**Dates Covered by the Report:** June 1997 - October 1997.

## Use of a Sugar Ester, Produced by AVA Chemical Ventures, as a Biorational Agent Against the Silverleaf Whitefly, *Bemisia argentifolii*, in Field Trials in Upland Cotton

Deltapine 5415 was planted and furrow irrigated in small plots 16 ft. in length and 6 rows across (40 in. rows). Plots were separated by 2 fallow rows and 8 ft. alleys. The sugar ester was used at 0.3%wt/v gal/ac. Seven weekly applications were made once the silverleaf whitefly reached the action threshold (Univ. AZ recommendations). This treatment was part of a 16-treatment random block design that included a "best agricultural practice regime," a water-treated control, and an adjacent 1-ac block control. Eggs, small nymphs, and large nymphs were sampled from leaves taken from 5 plants per plot, from the fifth main-stem leaf down from the first expanded terminal leaf. Each sample was counted from a 1-in. disk taken between the main leave stem and the next lateral vein. Adults were sampled from 30 leaves/plot, same location using a binomial decision of counting a leaf as positive if 3 or more adults were present. Weekly sweeps were taken in all plots for predators, parasites, and *Lygus* these collections and data are still being processed. Applications were made with a gasoline-driven back pack Solo™ sprayer at 20 psi and 30 gal./ac. The sugar ester was effective at controlling silverleaf whitefly immature life stages. It had a higher control efficacy than did the best agricultural practice regime although the differences were not statistically significant. It was similar to the entompathogenic fungi *Paecilomyces fumosoroseus* in efficacy. The seasonal mean reduction for 7-weekly applications was 5.7-fold less eggs and small nymphs, and 4.5-fold less large nymphs, than for the block control (all significant at $P<0.0001$, ANOVA). Yield was excellent and large bolls with non-sticky cotton were produced.

**Investigator's Name(s)**: S. J. Castle[1], M. González-Loc[2], R. León-López[2], N. Prabhaker[3], N. C. Toscano[3], and T. J. Henneberry[1]

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**Research & Implementation Area**: Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

**Dates Covered By The Report**: July-September, 1997

## Regional Comparison of Whitefly Responses to Danitol®+Orthene®: Reduced Susceptibility in Mexicali Valley

Differences in responses to various insecticides among regional populations of *Bemisia tabaci* in the southwestern USA and Mexicali Valley, B.C., Mexico have been detected the past few years using a yellow-sticky card bioassay technique. The widest range of responses by far has been to the insecticide mixture of Danitol®+Orthene®. This treatment has been used intensively to combat whitefly infestations in mid to late season cotton from 1993 in Arizona and 1994 in California and Mexico to the present. A significant difference in relative susceptibility to Danitol®+Orthene® between Imperial Valley, CA and Maricopa, AZ whiteflies was first observed in late season 1995. The following year, whiteflies collected at various times during the cotton season from the same two regions as well as from Yuma, AZ and Mexicali Valley displayed significant variation among locations. Over a five month period from July-November, mortalities at a diagnostic dose of 75 µg (a.i. Danitol®)/ml were consistently lower for Maricopa whiteflies than for any other location. Responses of whiteflies from the other three regions varied slightly, i.e. between 91-100% mortality at the diagnostic dose compared to <40% for Maricopa whiteflies in three out of five tests. Whiteflies from Mexicali and Yuma were generally slightly more susceptible to most insecticide treatments than ones from the Imperial Valley.

In 1997, whiteflies from four locations within four different fields were sampled in July and August in Imperial Valley and August and September in Mexicali. Four concentrations of Danitol®+Orthene® were used on each occasion. In Maricopa, the same number of concentrations and total sites were sampled, but all from one field divided into different treatment areas, and on three dates between July and September. The different concentration ranges that had been used according to region in 1996 were still sufficient in 1997 in Imperial Valley and Maricopa, i.e. no significant shift, higher or lower, in whitefly responses had occurred in either region. However, on the first test in Mexicali in 1997, the range of concentrations based on 1996 results proved to be too low as only the top concentration of 37.5 µg (a.i. Danitol®)/ml yielded average mortalities between 12-32% while the lowest three concentrations yielded average mortalities of <10%. Subsequently, a series of test concentrations were tried to identify a broader mortality range for the Mexicali whiteflies. The follow-up test in mid September confirmed the warning signal provided in August that greatly reduced susceptibility to Danitol® + Orthene® was being expressed in all sampling locations within Mexicali Valley. The fields that were sampled each month along Highway 2 (Km 10-32) revealed a pattern of higher to lower susceptibilities from west to east; cotton cropping intensity is greater on the east side of the valley.

Mean mortalities (%±sem) of whitefly adults from four fields (n=4 each field) at the concentration of 37.5 µg (a.i. Danitol®)/ml for Mexicali Valley on 8/27/97 were: 32±3, 31±2, 29±4, and 12±2. In contrast, mean mortalities of Maricopa whiteflies sampled 8/18/97 were: 45±7, 41±5, 33±3, and 31±4; for Imperial Valley whiteflies sampled 8/15/97: 68±3, 58±5, 58±4, and 56±3. In September, mean mortalities at the same concentration for Mexicali whiteflies from four fields on 9/19/97 were: 38±4, 26±3, 19±1, and 19±4. For Maricopa whiteflies collected 9/16/97, mean mortalities were: 45±8, 38±4, 35±6, and 33±8. A similar pattern of mortality vis a vis regional location was observed with the other concentrations of Danitol®+Orthene®.

Intraregional responses of Mexicali whiteflies in 1997 represent a significant departure from 1996. They presently represent the least susceptible of the interregional populations to Danitol®+Orthene®.

**Investigator's Name(s)**: S. J. Castle[1], P. C. Ellsworth[2], J. W. Diehl[2], and T. J. Henneberry[1]

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**Research & Implementation Area**: Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

**Dates Covered By The Report**: July-September, 1997

## Within Season Shift in Adult Whitefly Responses to Danitol®+Orthene® According to Insecticide Regimen

In conjunction with a comprehensive study assessing the quality of whitefly management based on different insecticide regimens (Ellsworth, Section F), responses of whiteflies to Danitol®+Orthene® in a yellow-sticky card bioassay were measured pre-, mid-, and post-spraying at the experimental site in Maricopa, AZ. Adult whiteflies tested in the bioassays were collected from each of four insecticide treatment regimens, replicated four times, that partitioned the 8-acre study field. Insecticide regimens were as follows: 1) Knack® first, followed by Applaud® and two non-pyrethroid combination sprays; 2) Applaud® first, followed by Knack® and two non-pyrethroid combination sprays; 3) 'IRM', consisting of three non-pyrethroid sprays and two pyrethroid sprays (Danitol®+Orthene® and Danitol®+Vydate®; 4) 'UTC', untreated control.

Four sets of yellow-sticky cards (one per replicate) were prepared for each insecticide regimen on each bioassay date. For the first (pre-spray) date, each set of four cards consisted of four concentrations: 0, 37.5, 150, and 600 µg (a.i. Danitol®)/ml. On the following two dates, a fifth concentration (2400 µg [a.i. Danitol®]/ml) was added to each set. The concentration (a.i.) of Orthene® on each card varied proportionally at 2.5 times the concentration (a.i.) of Danitol®.

Results of the first series of bioassays on 7/28/97 indicated few differences among whiteflies collected from the respective subplots assigned to the four insecticide regimens. Mean mortalities (%±sem) at the respective concentrations (0 to 600 µg [a.i. Danitol®]/ml) for the grouped data (n=16) were as follows: 2±0.5, 33±3, 71±2, and 78±2. Following the commencement of spraying, the second series of bioassays on 8/18/97 also showed few differences among treatment regimens in terms of whitefly susceptibilities to Danitol®+Orthene®. However, whiteflies on the whole proved to be slightly more susceptible in the second set of bioassays compared to the first as revealed by mean mortalities at the respective concentrations (0 to 2400 µg [a.i. Danitol®]/ml) in the following grouped data (n=16): 10±2, 38±3, 75±2, 86±1, and 94±0.5.

By the third series of bioassays on 9/16/97, a significant departure in responses of whiteflies collected from the IRM regimen relative to the other three regimens had taken place. A one-way analysis of variance followed by a Tukey-Kramer HSD procedure revealed significantly ($P<0.05$) lower mortalities at each of the four Danitol®+Orthene® concentrations (37.5 to 2400 µg [a.i. Danitol®]/ml) for whiteflies from the IRM regimen compared to the other three regimens. No other significant differences among treatment regimens were observed at any concentration. Thus, mean (n=4) mortalities of whiteflies from the IRM regimen relative to the grouped mean mortalities (n=12) from the other three regimens (IRM/Grouped) are as follows (for each concentration): 22±3/43±3, 25±6/75±2, 55±7/86±1, and 74±5/94±2.

With the backdrop of greatly reduced susceptibility to pyrethroid/organophosphate or carbamate combinations in central Arizona the past few years, the present results support the anti-resistance tactic of rotating to alternate chemistry to avoid further losses in susceptibility. The availability of the IGRs Knack® and Applaud® have benefitted efforts to combat pyrethroid resistance while improving whitefly management.

**Investigator's Name(s):** Eric T. Natwick.

**Affiliation & Location:** UC Cooperative Extension, UC Desert Research and Extension Center, Holtville, CA.

**Research & Implementation Area:** Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

**Dates Covered by the Report:** August 1997 through October 1997.

## Evaluation of Insecticides for Silverleaf Whitefly Control In Tomato

Tomato var. Peto Seed P-19 was sown at UC Desert Research & Extension Center 28 August 1997. Five insecticide treatments and an untreated control were replicated six times in a randomized complete design experiment. Insecticide treatments were as follows: Provado 1.6 Fat 0.05 lb ai/acre, acetamiprid 70 WP at 0.05 lb ai/acre, acetamiprid 70 WP at 0.075 lb ai/acre, Applaud 70 WP at 0.25 lb ai/acre plus Phaser 3 EC at 0.75 lb ai/acre alternating with Phaser 3 EC at 0.75 lb ai/acre, Applaud 70 WP at 0.38 lb ai/acre plus Phaser 3 EC at 0.75 lb ai/acre alternating with Phaser 3 EC at 0.75 lb ai/acre. Foliar sprays were applied on 9 & 19 September, and 1 October, 1997. Silverleaf whitefly, *Bemisia argentifolii*, were sampled by counting adults via leaf turn on ten plants at random from each plot on, 17, 24 & 30 September, 1997. Silverleaf whitefly eggs and nymphs were counted on 1.54 $cm^2$ of leaf surface from five tomato plants at random from each plot on 2, 17 & 24 September, and 2 & 6 October, 1997.

The seasonal mean values of adult whitefly for the acetamiprid 70 WP at 0.075 lb ai/acre and the Applaud 70 WP at 0.38 lb ai/acre plus Phaser 3 EC were lower than the untreated control while the other treatments did not differ significantly from the control. Acetamiprid 70 WP at 0.075 lb ai/acre had the lowest seasonal mean value for whitefly eggs, but there were no significant differences among the treatment means. The seasonal mean values of nymphs for the acetamiprid 70 WP at 0.075 lb ai/acre and the Applaud 70 WP at 0.38 lb ai/acre plus Phaser 3 EC were lower than the untreated control, but were not significantly different from the other insecticide treatments.

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**Research & Implementation Area:** Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

**Dates Covered by the Report:** August 1997 through October 1997.

## Silverleaf Whitefly Control In Fall Planted Cantaloupe Melons, 1997

A stand of Cantaloupe melons, var. Topmark, was established at UC Desert Research & Extension Center 25 August 1997. Ten insecticide treatments and an untreated control were replicated four times in a randomized complete design experiment. Insecticide treatments were as follows: Applaud 70 WP at 0.25 lb ai/acre, Applaud 70 WP at 0.38 lb ai/acre, Applaud 70 WP at 0.25 lb ai/acre plus Phaser 3 EC at 0.75 lb ai/acre, Applaud 70 WP at 0.35 lb ai/acre plus Capture 2 EC at 0.08 lb ai/acre, Capture 2 EC at 0.08 lb ai/acre plus Thiodan 3 EC at 0.75 lb ai/acre, Capture 2 EC at 0.08 lb ai/acre plus pymetrozine at 0.094 lb ai/acre plus fenoxycard at 0.063 lb ai/acre, and Danitol 2.4 EC at 0.20 lb ai/acre plus Orthene 75S at 0.50 lb ai/acre. Foliar insecticide treatments were applied three times at one week intervals from 5 September through 18 September and again two weeks later on 2 October 1997. Silverleaf whitefly, *Bemisia argentifolii*, were sampled by counting adults on the fifth leaf from the terminal of the main stem cane from ten plants at random in each plot via the leaf turn method on 2, 10, 16, 23 and 29 September, 1997. Silverleaf whitefly eggs and nymphs were counted on 1.54 $cm^2$ leaf disks from ten crown leaves extracted from randomly selected melon plants in each plot on 2, 10, 16, 23 and 29 September, and 7 October, 1997.

Adult levels were lowest in the treatments that included Applaud 70 WP and in the Capture plus Thiodan treatment, but the eggs numbers were lowest in the Capture plus pymetrozine plus fenoxycarb and the Danitol plus Orthene treatments. The lowest levels of crawlers followed the Capture plus Thiodan, Capture plus Applaud and Danitol plus Orthene treatments. The Applaud at 0.38 lb ai/acre treatment had the lowest levels of nymphs followed by Danitol plus Orthene.

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**Research & Implementation Area:** Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

**Dates Covered by the Report:** March 1997 - June 1997.

## Silverleaf Whitefly Control In Spring Planted Cantaloupe Melons, 1997

A stand of Cantaloupe melons, var. Topmark, was established at UC Desert Research & Extension Center 26 March 1997. Three insecticide treatments and an untreated control were replicated four times in a randomized complete design experiment. Insecticide treatments were as follows: Nexter 75 WP at 0.30 lb ai/acre, Nexter 75 WP at 0.40 lb ai/acre, and Provado 1.6 F at 0.05 lb ai/acre. Foliar insecticide treatments were applied four times at one week intervals from 13 May through 3 June 1997. Silverleaf whitefly, *Bemisia argentifolii*, were sampled by counting adults on the fifth leaf from the terminal of the main stem cane from ten plants at random in each plot via the leaf turn method on 12, 19 & 26 May and 2 & 9 June, 1997. Silverleaf whitefly eggs and nymphs were counted on 2.54 $cm^2$ leaf disks from ten crown leaves extracted from randomly selected melon plants in each plot on 9, 19 & 26, and 2 & 9 June 1997.

Adult levels were not significantly different among the treatments on any of the sampling dates. Mean separations for whitefly eggs only occurred on 27 May when Nexter 75 WP at 0.40 lb ai/acre and Provado 1.6 F were lower than the other two treatments. Mean separations for nymphs occurred on 2 June when Nexter 75 WP at 0.40 lb ai/acre and Provado 1.6 F were lower than the untreated control and on 9 June when both rates of Nexter 75 WP and Provado 1.6 F were lower than the untreated control.

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**Research & Implementation Area:** Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

**Dates Covered by the Report:** March 1997 through December 1997.

## Silverleaf Whitefly Control In Cotton, 1996

A stand of cotton, var. DPL 5415, was established at UC Desert Research & Extension Center 28 March 1997. Sixteen insecticide treatments and an untreated control were replicated four times in a randomized complete design. Insecticide treatments were as follows: Naturalis-L at 10 fl oz/acre, Naturalis-L at 10 fl oz/acre plus Phaser 3 EC at 1.13 lb ai/acre, Phaser 3 EC at 1.13 lb ai/acre, Knack 0.86 EC at 0.054 lb ai/acre, Knack 2.9 EC at 0.054 lb ai/acre, Knack 0.86 EC at 0.054 lb ai/acre plus pymetrozine at 0.094 lb ai/acre, pymetrozine at 0.094 lb ai/acre plus fenoxycarb at 0.063 lb ai/acre, Applaud 70 WP at 0.35 lb ai/acre, Applaud 50 WP at 0.35 lb ai/acre, Applaud 70 WP at 0.25 lb ai/acre plus Phaser 3 EC at 1.13 lb ai/acre, Phaser 3 EC at 1.13 lb ai/acre plus Ovasyn 1.5 EC at 0.25 lb ai/acre, Nexter 75 WP at 0.30 lb ai/acre, acetamiprid 70 WP at 0.05 lb ai/acre, acetamiprid 70 WP at 0.075 lb ai/acre, acetamiprid 70 WP at 0.10 lb ai/acre, and Danitol 2.4 EC at 0.20 lb ai/acre plus Orthene 90S at 0.50 lb ai/acre. Helena Buffer PS at 23.6 ml/5 gal. and Sylgard 309 at 5.9 ml/5 gal. were used with all insecticide spray treatments. Foliar insecticide treatments were applied seven times at weekly intervals starting 18 June through 30 July 1996. Acetamiprid was not applied on 9, 16, and 23 July. Silverleaf whitefly adults were sampled from ten plants at random in each plot via the leaf turn method using the fifth main stem leaf from the terminal on 12, 17 & 24 June, and 1, 8, 15, 22 & 29 July and 5 & 12 August 1997. Silverleaf whitefly eggs and nymphs were counted on 1.54 $cm^2$ leaf disks from 5th position, main-stem terminal leaves extracted from ten randomly selected plants in each plot on 12, 17 & 24 June, and 1, 8, 15, 22 & 29 July and 5 & 12 August 1997. Yield data were recorded on 3 September 1997. Seed cotton was hand picked from 0.002 acre per plot. Seed cotton samples were ginned at the USDA-ARS Western Cotton Research Laboratory in Phoenix, AZ and lint samples were sent to the USDA/ARS Cotton Quality Research Station in Clemson, SC for stickiness and sugar analysis.

There were no differences for numbers of whitefly adults eggs or nymphs among the plots to receive insecticide treatments and the control on 12 and 17 June prior to insecticide treatments. Seasonal adult means for all treatments were lower than the untreated control with the following exceptions: Applaud 70 WP, Knack 0.83 EC, pymetrozine 50 WP plus Knack 0.86 EC, Naturalis-L, and Applaud 70 WP plus Phaser 3 EC. The seasonal mean for adult whitefly was lower in the acetamiprid 70 WP at 0.10 lb ai/acre than all other treatments with the following exceptions: acetamiprid 70 WP at 0.075 lb ai/acre, Danitol plus Orthene, Nexter 75 WP, and pymetrozine 50 WP plus fenoxycarb. All of the insecticide treatments had seasonal mean values for nymphs that were lower than the untreated control. Knack 2.9 EC had a seasonal mean value for whitefly nymphs that was lower than all other insecticide treatments with the following exceptions: all rates of acetamiprid, Applaud 70 WP plus Phaser 3 EC, Danitol plus Orthene and Phaser 3 EC at 1.13 lb ai/acre.

**Investigator's Names**: N. Prabhaker[1], Nick. Toscano[1], T. J. Henneberry[2], D. Scott Lawson[3] and K. Jones[3]

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**Research & Implementation Area**: Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

**Dates Covered By The Report**: May-October, 1997

## Evaluation of Biological Activities of CGA-293343 and CGA-215944 (Fulfill™) Against Silverleaf Whiteflies on Cotton

The effectiveness of two new compounds, CGA-293343 and CGA-215944 (Fulfill™), was evaluated for adult and larval toxicity against two strains of silverleaf whiteflies, an imidacloprid resistant strain (IM-R) and a susceptible strain (REF) on cotton. The toxicity of the two compounds was compared to imidacloprid and nicotine against the IM-R strain of whiteflies. Differences in responses to the two insecticides were detected in both REF and IM-R whiteflies. The compound CGA-293343 was the most toxic to adults of the IM-R strain of whiteflies when applied as a foliar spray. However, toxicity decreased when applied as a systemic. The compound CGA-293343 was effective at $LC_{90}$ 40 mg/ml to the IM-R adults in 24 h as a foliar spray which decreased further to 0.6 mg/ml in 48 h. Toxicity was higher in the REF strain with an $LC_{90}$ of 110 mg/ml at 24 h but reduced similarly to that of the IM-R strain in 48 h to 1 mg/ml showing a resistance ratio of 1.4. The $LC_{90}$ was higher at 140 mg/ml when CGA-293343 was applied as a systemic against the IM-R adults. However, toxicity decreased in 48 h to 9 and 12 mg/ml for the REF and IM-R strains, respectively. Fulfill™ was not as effective as CGA-293343 to the IM-R adults. In 48 h, the $LC_{90}$ to Fulfill™ was high at 3990 mg/ml to the resistant whiteflies as a foliar spray but decreased to 700 mg/ml in 48 h. As a systemic it was even less effective with an $LC_{90}$ of 12,790 mg/ml in 48 h, which decreased dramatically to 550 mg/ml in 72 h. Nicotine was not effective as a foliar spray against the IM-R strain in 24 h ($LC_{90}$ = 6770 mg/ml) but it appeared to be more toxic after 72h ($LC_{90}$ = 50 mg/ml).

The compound CGA-292343 was extremely effective against the immatures of the IMR strain of whiteflies as indicated by the low $LC_{90s}$ 9 and 40 mg/ml for foliar and systemic treatment respectively. Fulfill™ was less effective than 293343 against the IM-R immatures, but slightly more effective as a foliar spray ($LC_{90}$ = 90 mg/ml) than as a systemic ($LC_{90}$ = 300 mg/ml). Nicotine was the least effective compound against the immatures of the IM-R strain with a high $LC_{90}$ of 700 and 1800 mg/ml for foliar and systemic treatments respectively.

The absence of any difference between strains in $LC_{90s}$ at 48 h for CGA-292343, suggests that there is little cross-resistance in the IM-R strain (RR = 107) to CGA-293343. These findings are beneficial from both pest management and resistance management perspectives. The results indicate that in spite of some similarity in chemistry between imidacloprid and CGA-293343, the latter affects the IM-R strain differently than does imidacloprid with no cross-resistance. However, these conclusions are applicable only to this strain and cannot be generalized as to how cross-resistance might be exhibited in field populations. Fulfill™ appears to be slow acting against whiteflies with longer residual activity since the lowest $LC_{90}$ was observed after 72 h.

**Investigator's Name(s):** Alvin M. Simmons and D. Michael Jackson.

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**Research & Implementation Area:** Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

**Dates Covered by the Report:** 1997.

## Ultrasonic Fogging Device: Managing Whiteflies in Greenhouses

Research was continued on evaluating the usefulness of an ultrasonic fogging device as a delivery system for low dosages of insecticides for managing whiteflies in a greenhouse production system. No other research group has examined this device as an insecticide applicator. We reported in 1996 that this fogger can effectively deliver contact insecticides to the under surface of leaves at reduced rates. Work in 1997 was continued on establishing a dose-mortality curve for foliar imidacloprid (Provado 1.6) against adult whiteflies. All tests were conducted on *Bemisia argentifolii* on collard plants. The fogger produces moisture droplets about 5 microns in diameter, which behave like a gas. The fogger was run for six minutes for each trial in a 6.1 m by 4.6 m plastic covered greenhouse. Whiteflies on plants in an untreated greenhouse were used as a control. Good whitefly control was obtained within 24 hours at rates much less than the label rate of 112 g ai/ha. Using the fogger device, the $LD_{90}$ on the whiteflies was 27.0 g ai/ha. This fogger may also have applications for greenhouse commodities other than vegetables. Moreover, it could be used to target other greenhouse insect pests with low-volumes of environmentally friendly insecticides. This fogger applicator seems to be a convenient and economical method of managing whiteflies in a greenhouse production system.

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**Research & Implementation Area**: Section C: Chemical Control, Biorationals, and Pesticide Application Technology

**Dates Covered By The Report**: 1997

**Responses to Azadirachtin and Pyrethrum by Two Species of *Bemisia* (Homoptera: Aleyrodidae)**

The effects of pyrethrum and azadirachtin on the ovipositional responses of *Bemisia argentifolii* Bellows & Perring and *Bemisia tabaci* (Gennadius) were determined in the laboratory. Choice and no-choice tests revealed that neither *B. argentifolii* nor *B. tabaci* females preferred to alight and oviposit on bean plants treated with pyrethrum. In contrast, the number of *B. argentifolii* females that alighted on control versus azadirachtin-treated plants was not significantly different in all but 1 instance. When given a choice, significantly fewer *B. tabaci* females landed on azadirachtin-treated plants at observation hours 6, 8, and 24. In no-choice trials, numbers of *B. tabaci* females alighting on control versus azadirachtin-treated plants were equivalent throughout the entire test period. Moreover, although *B, argentifolii* ovipositioned equal numbers of eggs on control and azadirachtin-treated plants in choice and no-choice trials, *B. tabaci* females laid significantly fewer eggs on plants treated with azadirachtin. Percentage nymphal establishment of *B. argentifolii* on control versus azadirachtin-treated plants was not significantly different in choice and no-choice trials. Although the percentages of established *B. tabaci* nymphs were the same on control and azadirachtin-treated plants in the no-choice test, a significantly lower percentage of nymphs were found on treated plants in the choice trials.

**Investigator's Names**: Nick Toscano, N. Prabhaker, S. Zhou and G. Ballmer

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**Research & Implementation Area**: Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

**Dates Covered By The Report**: June-October 1997

## Toxicity of Applaud® And Knack® Against Silverleaf Whiteflies From Southern California: Implications For Susceptibility Monitoring

A survey of silverleaf whitefly populations from different cotton growing regions in California was conducted in 1997 to establish baseline toxicological responses to Applaud® and Knack®. Both compounds proved to be highly toxic even in minute quantities. Geographical and temporal variation in responses to each product was observed, but generally was within the range of normal fluctuation. Although all the whitefly populations tested appear to be highly susceptible to Applaud®, there were regional differences in susceptibility. $LC_{50}$s ranged from 0.0023 to 0.065 µg (AI)/ml for the whiteflies from the three valleys. No striking differences were found in whitefly responses from Imperial and Palo Verde Valleys as observed by similar $LC_{50}$s ranging from 0.0023 to 0.008 µg (AI)/ml, approximately a 3-fold difference. One possible exception was the consistently higher $LC_{50}$s observed in San Joaquin Valley whiteflies compared to either Palo Verde Valley or Imperial Valley whiteflies, the $LC_{50}$s ranging from 0.026 to 0.039 µg (AI)/ml, showing a difference in toxicity of upto 28-fold.

A fairly wide range in sensitivity to Knack® by whiteflies from the three locations was observed. $LC_{50}$s ranged from 0.00003 to 0.010 µg (AI)/ml for Knack®. In general, Knack® was more toxic to whiteflies than Applaud® as seen by the lower $LC_{50}$s, but with one exception. Out of three field sites surveyed in Palo Verde Valley, whiteflies from one site showed the highest $LC_{50}$ of 0.010mg (AI)/ml. Whitefly populations from San Joaquin Valley were the most susceptible to Knack® as indicated by the lowest $LC_{50}$s recorded at 0.00003 to 0.0001 µg (AI)/ml.

Future surveys will help to establish whether variation in responses to Applaud® and Knack® is due principally to inherent differences among geographical populations or to agro-environmental conditions.

**Investigator's Name(s)**: Kai Umeda, C.C. Chu, and T.J. Henneberry.

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**Research & Implementation Area**: Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

**Dates Covered by the Report**: 1996-1997.

## Comparison of Leaf-Turn and CC Trap Methods to Estimate Adult Whitefly Densities in Commercial Spring Melon Fields

In 1996 and 1997, 17 commercial melon fields were monitored using leaf-turn and CC traps to detect developing whitefly infestation and assist growers in the decision-making process to manage whitefly populations. In 1996, in 5 melon fields from April to June, the CC trap compared favorably with the leaf-turn method. In 1997, the CC trap whitefly counts correlated favorably with the leaf-turn adult counts in only 2 of the 7 monitored cantaloupe fields. Also in 1997, CC trap whitefly counts were correlated to the leaf-turn method 3 of 5 monitored watermelon fields. The CC trap is another tool that offers the potential to assist growers and crop consultants in surveying and estimating the influx of whiteflies into melon crops.

## Research Summary

### Section C. Chemical Control, Biopesticides, Resistance Management, and Application Methods

Compiled by Philip A. Stansly

Widespread use of the systemic insecticide imidacloprid in vegetables and ornamentals coupled with use of the insect growth regulators (IGRs) buprofezin and pyriproxyfen in cotton are probably the principal factors that have lead to a lessening of crop losses due to whitefly in many areas. These products have done much to stabilize pest management in agricultural systems where *Bemisia* is a key pest. Use of broad-spectrum insecticides has been reduced, opening the door to a greater role for biological control in managing pests on these crops. Most whitefly management still depends on chemical control and thus is subject to the specter of insecticide resistance. A number of promising systemic materials are poised to enter the market with active ingredients classified as "neonicotinoids" and similar in mode of action to imidacloprid. The advent of these compounds raises a concern that possible cross resistance will hasten whitefly tolerance to the entire class of neonicotinoids.

Given the present dependence on chemical control, monitoring and management of whitefly tolerance to insecticides continues to be a primary area of focus. Utilization of IGRs on cotton there has alleviated pressure on more traditional chemistries, at least temporarily. A consequent increase in susceptibility of whitefly populations has been observed in central Arizona that previously demonstrated high resistance levels. Similar increases in susceptibility to conventional insecticides were observed in large scale field evaluations that included one or more treatments with an IGR. Baseline tolerances for buprofezin and pyrpriproxyfen have been obtained, and it is hoped that restriction to one application of each per season in cotton will reduce the selection rate for resistance to inconsequential levels. Baseline tolerances for imidacloprid have also been obtained by a number of bioassay methods and sensitivity to this compound is being actively monitored, albeit without total agreement on the most appropriate method. The concern over possible cross resistance between neonicotinoids is also being actively investigated by the companies in question as well as externally, although no clear conclusions have yet been published. However, advances have been made in understanding the biochemical mechanism responsible for activity of this class of compounds with the recent discovery of a nicotinic acetylcholine receptor.

Insecticide resistance management as commonly conceived seems to be limited to ways of using insecticides (rotations, tank mixes, etc.) to limit selection against particular modes of action. The relative benefit of each one of these is often uncertain and therefore controversial, but no one can argue that avoiding insecticides is not an effective means of avoiding selection pressure. Action thresholds are clearly effective tools to accomplish this by avoiding unnecessary applications of insecticide. However, thresholds are a function, in part, of insecticide efficacy and therefore should be updated as new materials come on line. Action thresholds to avoid yield losses in cotton have been developed and implemented based on densities of adults and nymphs as estimated by sequential sampling procedures. Surpassing the threshold triggered a spray of tank mixes of traditional chemistries. Existing thresholds might be increased with availability of the more efficacious IGRs. However, quantifying the relationship between whitefly populations and sticky cotton remains an elusive goal, because of mitigating factors related primarily to weather, especially rainfall. Interest continues to increase in evaluating the role of insecticide-free refuges to reverse trends toward increasing resistance of whitefly populations with a view toward future manipulation of this key ecological factor.

Interest continues to grow in the concept of integrating biological control with compatible "biorational" insecticides. Reports of new biorational insecticides recently developed and tested include extracts of petunia and chinaberry (*Melia azedarah*), antibiotics that interfere with normal functioning of symbiotic bacteria, and benzyl phenol urea. Antibiotic insect suppression is perhaps the furthest from practical utilization but nevertheless offers promise as a novel approach to pest management. The compatibility of IGRs with natural enemies remains an open question. For example, compatibility has been clearly demonstrated in the case of pyriproxyfen with certain aphelinid parasitoids of *Bemisia* such as *Encarsia pergandiella*, but is more questionable with others such as *E. formosa*. Field evaluations of interactions between parasitoid activity and the IGRs fenoxycarb in Florida and pyriproxyfen and buprofezin in Arizona have demonstrated no incompatibilities. Evaluations in Arizona were made using partial life tables to partition the effects of different mortality factors including insecticidal control. This method provides a more realistic picture of impacts on populations compared to simple counts. In contrast to the situation with whitefly parasitism, there are some disturbing of persistent disruption of coccinellid predation and consequent resurgence of mealybugs and other homopteran pests in citrus after applications of pyriproxyfen. However, fenoxycarb treatment followed by releases of coccinellids has been demonstrated in cage studies to provide better control of whiteflies than either the IGR or the beetles alone.

Many traditional biorational insecticides such as soaps and oils, as well as biopesticides such as the entomopathogen *Beauvaria bassiana* function strictly by contact and require good underleaf coverage to be effective against whiteflies. No novel spray technologies have been reported although there were some advances in the area of evaluation with the use of sticky paper targets to estimate deposition of spray material on leaf surfaces. Low and high volume sprayers, with and without air assist or electrostatics, continue to be evaluated, with no clear advantages demonstrated for any in terms of underleaf coverage. The traditional hydraulic sprayer, well calibrated and supplied with the appropriate drop nozzles, is still as viable an alternative as any. One controlled study showed that the best canopy penetration was usually obtained at relatively high volumes and pressures. In regard to the neonicotinoids, soil as opposed to foliar application continues to give best results, even though methods of application to the soil are often primitive, thus presenting opportunities for improved technology.

**Table C. Chemical Control, Biopesticides, Resistance Management, and Application Methods.**

| Research Approaches[a] | Year 1 Goals Statement | Progress Achieved Yes | Progress Achieved No | Significance |
|---|---|---|---|---|
| **Improve insecticide efficacy:** | | | | |
| **Develop, test, and assist in the registration of insecticides, biorationals, and natural products.** | Develop new chemistries and natural products. Develop improved techniques for evaluating efficacy of insecticides. Support registration of desirable new products by providing information to regulatory agencies. | X | | New studies reported in this area in 1997 = 39. New biopesticides like *Petunia* extract and *Melia* extract tested. New biorationals tested or reported on included benzyl phenal urea napthaphenol and antibiotics (to act against symbiotic bacteria). |
| **Develop improved methods of application including formulation and delivery of materials to improve control.** | Develop spray systems for better underleaf coverage. Evaluate rates, timing, placement in relation to efficacy. Consider formulation, UV protectants, and other means to improve efficacy. Develop improved methods to evaluate application efficacy. Field test under commercial conditions for technology transfer. | X | | New studies = 10. Thermal fogger evaluated for greenhouse use. However, a comparison of five-sprayers in the field trials showed no significant differences between hydraulic, air-assist and electrostatic technology. |
| **Conserve insecticide efficacy:** | | | | |
| **Relate action thresholds to insecticide usage patterns.** | Refine action thresholds based on insecticide efficacy and input from other control strategies. | X | | New studies = 8. Cost-benefit study of IPM system in cotton. Life table approach to evaluate impact of mortality factors initiated. Training effort to extend threshold information to growers in Arizona. |
| **Elucidate the role of genetic, biochemical and ecological factors leading to insecticide resistance.** | Establish whitefly strains resistant and susceptible to various classes of insecticide. Conduct studies to determine the genetics and biochemistry of resistance and cross resistance to different classes of insecticide. | X | | New studies = 4. Imidacloprid binding site elucidated. Studies completed on stability of resistance in *Bemisia* including agricultural and ecological factors. |

**Table C. Chemical Control, Biopesticides, Resistance Management, and Application Methods. (Continued)**

| Research Approaches[a] | Year 1 Goals Statement | Progress Achieved Yes | Progress Achieved No | Significance |
|---|---|---|---|---|
| **Improve insecticide efficacy:** | | | | |
| **Improve techniques for monitoring resistance.** | Establish baseline data on toxogenic responses of whitefly populations to new insecticides. | X | | New studies = 9. Bioassays developed for testing sensitivity to imidacloprid. Baseline data obtained on sensitivity to imidacloprid and IGRs pyriproxyfen and buprofazin. |
| **Develop, evaluate and refine resistance management systems.** | Evaluate the effects of mixtures and rotations of new and old chemistries to mitigate selection for resistance. | X | | New studies = 14. Area-wide plans for management of resistance refined in Arizona and California. Large-scale trials of resistance management strategies conducted. |
| **Integrate chemical control with other tactics.** | Evaluate selectivity of synthetic insecticides and natural products to key whitefly natural enemies. | X | | New studies = 10, including laboratory and field studies on compatibility with whitefly natural enemies. Also a study on effects of pyrethroids on anitbiotic factors bred into crops. |

[a] See Table A for complementary research on thresholds.
[a] See Table B for complementary research on virus/vector interactions.
[a] See Table D for complementary research on biological control.
[b] See Table E and F for complementary research on systems management.

**Section D: Natural Enemy Ecology and Biological Control**
Co-Chairs: Kevin Heinz and Charles Pickett

**Investigator's Name(s):** D. H. Akey and T. J. Henneberry.

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**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** June 1997 - October 1997.

## Use of the Entomopathogenic Fungi, *Beauveria bassiana* and *Paecilomyces fumosoroseusas,* as Biorational Agents Against the Silverleaf Whitefly, *Bemisia argentifolii,* in Field Trials in Upland Cotton

Deltapine 5415 was planted and furrow irrigated in plots 192.5 ft. in length and 6 rows across (40 in. rows). Plots were separated by 2 fallow rows and 8 ft. alleys. *Beauveria bassiana* as Naturalis®, Troy Biosciences Inc. at 10 oz. Product/ac, $2.3x\ 10^7$ conidiia/ml was used at full rate as single product applications. Dual treatments with *Beauveria bassiana* and endosulfan (AgrEvo Co., Phaser® 3EC—0.75 lbs. Ai/ac) used each product at 1/2 rate. *Beauveria bassiana* as Mycotrol®, Mycotech Corp., 0.5 lbs./ac, $2 \times 10^{13}$ spores/lb. was used at full rate as single product applications. Dual treatments with *Beauveria bassiana* and endosulfan (Gowan Endosulfan 50 WSB 0.75 lbs. Ai/ac) used each product at 1/2 rate. *Paecilomyces fumosoroseus* PFR- 97® Thermo Trilogy Corp., 0.025 lbs./gal., $1x\ 10^9$ CFU (spores)/gm equivalent 20% product was used in one trial only at the rate given. These treatments were part of a 16-treatment random block design that included a "best agricultural practice regime," a water-treated control, and an adjacent 1-ac block control. Eggs, small nymphs, and large nymphs were sampled from leaves taken from 5 plants per plot, from the fifth main-stem leaf down from the first expanded terminal leaf. Each sample was counted from a 1-in. disk taken between the main leave stem and the next lateral vein. Adults were sampled from 30 leaves/plot, same location using a binomial decision of counting a leaf as positive if 3 or more adults were present. Weekly sweeps were taken in all plots for predators, parasites, and *Lygus*; these collections and data are still being processed. Applications were made by ground with 3 nozzles/row; 1 overhead, and 2 with swivel nozzles angled upward on drops. Sprays were applied at 80 psi and 30 gal./ac. Both formulations of *Beauveria bassiana* were effective and similar in efficacy at controlling immature silverleaf whiteflies when used alone. The seasonal mean reduction for 8- weekly applications showed that both formulations were somewhat enhanced by endosulfan- for control of small and large nymphs; but the increased efficacy was not statistically significant. Compared to the block control, the efficacy of all 3 entomopathogenic fungi was significant at $P<0.0001$, ANOVA. Yield was excellent and large bolls with non-sticky cotton were produced.

**Investigator's Name(s):** Matthew A. Ciomperlik & Lloyd E. Wendel.

**Affiliation & Location:** USDA APHIS PPQ, Mission Biological Control Center.

**Research and Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** 1997.

## Regional Population Dynamics of Sweetpotato Whitefly (*Bemisia tabaci*, biotype B) in the Lower Rio Grande Valley of Texas.

Two transects were established in the Lower Rio Grande Valley of Texas to monitor Sweetpotato whitefly adult populations via sticky traps. Highways or Farm to Market (FM) roads were selected that transect the LRGV in an east to west direction. The selection criteria were: that the roads would pass through areas that are predominantly devoted to agriculture, would minimize sampling around municipalities or urbanized areas, and that bordered areas with a random mixture of vegetable, cotton and grain crops. Highway 281 and FM 1925 met the criteria; and areas were selected within those two roads that covered intensive agriculture in Hidalgo and Cameron counties.

Twenty one sticky traps were placed along FM 1925 and twenty four traps were placed along highway 281 (Fig. 1). Yellow sticky traps (7.5 cm x 7.5 cm or 58 $cm^2$ card, Olson, Medina, OH) were placed vertically 0.5 m above the ground at 3.2 km (2 mile) intervals along the highway. Traps were positioned within grassy or bare ground areas > 20 m from the nearest crop to sample more migrating whitefly adults than adults flying with plant canopies. Traps were changed once per week, and the sample trap was returned to the laboratory for counting. Each trap was examined under a stereo microscope and the number of adult whitefly were counted. The number of adult whitefly per trap was divided by the surface area (58 $cm^2$) to yield the number of whitefly adults trapped per $cm^2$. This value was averaged by highway in order to monitor population trends.

The data gathered in this study will supplement or build on the information gathered from 1991 through 1995 (Riley & Ciomperlik 1997, Envir. Ent. 26: 1049-1055). Overall, whitefly populations in the LRGV were lower in 1997 than those experienced in the 'breakout' years of 1991 and 1995. Population trends for whitefly in 1997 were similar to those of 1993 and 1994. Two population peaks were observed, the first major peak began in early June and persisting through the end of August, and a second minor peak beginning in early September and ending in early October. The first major peak of migrating whitefly was associated with spring melon harvesting in late May and early June, and defoliation of cotton in August. The second peak in whitefly numbers is not as easily attributable to any major cropping trends, rather it may be explained as a secondary migration of F1 individuals from the first migration peak.

**Investigator's Name(s):** John A. Goolsby[1] & Jesus Vargas Camplis[2].

**Affiliation & Location:** [1]USDA APHIS PPQ, Mission Biological Control Center
and [2]SARH-INIFAP, Campo Experimental, Rio Bravo, Tamaulipas, Mexico.

**Research and Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** 1997.

## Conservation of *Bemisia* Natural Enemies in Mexican Okra Fields

*Bemisia tabaci* (Biotype "B") is a problem pest throughout the overlapping agroecosystem of the Lower Rio Grande Valley floodplain. Okra serves as an excellent host for *Bemisia* and is planted almost exclusively on the Mexican side of the Valley along a narrow strip (8000 acres) adjacent to the Rio Grande River. Okra, depending on how it is managed, can potentially be a major source for *Bemisia* or a field insectary for natural enemies. Key to management of okra is the use of malathion and carbaryl. Our program was designed to show growers that 'traditional' prophylactic treatments of okra with broad-spectrum insecticides were not needed.

To accomplish the task of changing an established cultural practice, we enlisted the support of local agricultural consultants, key growers and U.S. importers. Five okra fields were selected for monitoring of whitefly population levels. All five growers had agreed to withhold applications of insecticide unless justified by high whitefly or aphid pressure. Field sampling began in May of 1997. As of September, none of the growers had applied insecticide. Density of 4th instar *Bemisia* nymphs remained below five nymphs per leaf (mean leaf size 760 $cm^2$) throughout the growing season, with predation accounting for 75% of mortality during May and June. From July-Sept., parasitism, predominantly *Encarsia pergandiella*, accounted for 60% of mortality. Although we were unable to gather comparative data (with malathion/ carbaryl applications), this represents the first season okra has been grown in Northern Tamaulipas without traditional prophylactic treatments. We intend to monitor the same fields next year and measure the impact of insecticide use on *Bemisia* and its natural enemies.

**Investigator's Name(s):** John A. Goolsby[1] & Matthew A. Ciomperlik[1].

**Affiliation & Location:** [1]USDA APHIS PPQ, Mission Biological Control Center.

**Research and Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** 1997.

## Field Evaluation of Banker Plants for Field Delivery of Parasitoids in Cucurbit Crops

Greenhouse grown seedling transplants inoculated with parasitoids "banker plants" were evaluated in both spring cantaloupes and fall watermelons. A portion of the seedlings can be inoculated with SPWF and selected parasitoids prior to transplanting. This methodology allows for more efficient early season release of known numbers of parasitoids in precise synchrony with the crop. Banker plant technology can be integrated with imidacloprid - AdmireÆ for season long control of *Bemisia* thus avoiding late season applications of broad-spectrum insecticides. Elimination of late season insecticides in melons greatly increases the numbers of parasitoids available to migrate into cotton.

Field tests of banker plants were conducted in 10 acres of spring melons at the Mission Biological Control Center Demonstration Farm. A ratio of one banker plant to 10 regular transplants was used for delivery of the parasitoids. Banker plants were inoculated with *Eretmocerus* sp. (M95012 - Pakistan). A mean rate of 76.1 +/- 45.3 parasitoids per banker plant delivered an estimated 68,946 parasitoids per acre. A dispersal study using yellow sticky traps (n = 300) and fluorescent dust to mark parasitoids emerging from banker plants was conducted. Traps were placed in a grid along the release row and adjacent six rows. Over a two day period, during emergence of the F2 generation, 25% of the marked parasitoids (n = 3), which were recovered, had dispersed from the release row. Recoveries were made upwind 1 row and downwind 2 rows. In contrast, 75% of the parasitoids (n = 9) were recovered on the release row. It appears from this preliminary data that parasitoids disperse adequately to the adjacent non-banker transplants and that dispersal appears to be localized within the crop. Yield estimates of vines (n = 30) from banker plants vs. regular transplants showed no differences in size or quantity of cantaloupes.

Field tests of banker plants 180 acres of fall seedless watermelons were conducted with growers in Mission and Falfurrias, TX. Banker plants were evenly distributed with the regular transplants at a ratio of 1:27. Pollinator watermelon transplants were used for the banker plants. A mean rate of 40.8 +/- 38.6 parasitoids per banker plant produced an estimated 6000 per acre. The mean level of parasitism in the banker plant fields was higher, over the entire season, as compared to the paired conventional fields. A dispersal study using yellow sticky traps (n = 100) was conducted in October following harvest of the watermelons. Over a two day period 56.2 % (n = 24) of the parasitoids recovered in the adjacent cucumber field were the exotic *Eretmocerus sp.* (M95012-Pakistan). This data shows dispersal of the exotic parasitoids from the watermelon crop, where they were introduced via banker plants, to the next crop -- cucumbers.

**Investigator's Name(s):** John A. Goolsby [1], Alan Kirk [2], and Lloyd E. Wendel[1].

**Affiliation & Location:** [1]USDA-APHIS-PPQ, Mission Biological Control Center; [2]USDA-ARS European Biological Control Center.

**Research and Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** 1997.

## Importation of Exotic Natural Enemies for *Bemisia tabaci* (Biotype "B")

During 1997, collections of natural enemies were received into the Mission Biological Control Center Quarantine Laboratory form Spain (Canary Islands), Ethiopia, and South Africa. From the Canary Islands, two aphelinid parasitoids, *Eretmocerus mundus* and *Encarsia transvera* and one drosophilid predator, *Achleotoxensus formosus* Loew were recovered. The aphelind parasitoids were duplicate species and not continued in culture. Host range specificity and biological studies are being conducted in quarantine on *A. formosus*. The *Eretmocerus* spp. recovered from Ethiopia and South Africa did not rear in quarantine.

Natural enemies imported into the MBCC quarantine follow a set protocol which maximizes the number of unique species or biotypes cultured. Natural enemies from collectors are isolated into separate emergence containers by date, geographic location, and host plant. Individuals from each of the different genera or species are isolated from *Bemisia* immatures for analysis. Parasitoid adults from each potential culture are collected for characterization by both molecular geneticists and taxonomists. Individuals from each isolation can be characterized by DNA patterns within days after importation using RAPD-PCR while taxonomic identifications are in progress. The DNA patterns allow us to identify genetically unique populations of natural enemies and avoid duplicate cultures of similar organisms.

Exploration for natural enemies of *Bemisia* has been conducted in the Mediterranean Region, South Central and Southeast Asia, and South America, the Arabian Peninsula and parts of Africa. Future exploration efforts during 1998 for additional natural enemies of *Bemisia* by USDA will likely be limited.

**Investigator's Name(s):** John A. Goolsby[1] & Walker Jones[2].

**Affiliation & Location:** [1]USDA-APHIS-PPQ, Mission Biological Control Center and [2]USDA-ARS-Benficial Insects Laboratory.

**Research and Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** 1997.

## Survey for Exotic *Bemisia* Parasitoids in the Lower Rio Grande Valley of Texas Using Sentinel Plants

A new technique for detecting establishment of exotic SPWF parasitoids using 'sentinel plants' has been developed by Jones (ARS-Weslaco). Sentinel plants are pre-infested with whitefly and placed in field locations to attract parasitoids and then returned to the lab for development and identification of the parasitoids. This technique has two major advantages: 1) sentinels can be placed quickly in many field locations for recovery of parasitoids, 2) sentinels give a true measure of primary parasitism without the masking effects of hyperparasitism by *Encarsia pergandiella*.

Ten locations throughout the Lower Rio Grande Valley of Texas (LRGV) were selected for monthly sampling of parasitoids using the sentinel method. Five of the ten release sites were locations where exotic parasitoids had been recovered within the past year. The remaining five sites were at least 5 miles distant from release sites. Ten sentinel plants were placed in each location for a period of three days. Plants were returned to the lab for development of the parasitoids. *Encarsia pergandiella* pupae on each leaf were counted and removed prior to emergence to avoid hyperparasitism of the *Eretmocerus* pupae. *Eretmocerus* adults were slide mounted for identification of exotic and native species.

Sampling began in May of 1997 with sporadic recoveries of exotic *Eretmocerus* through August. In September, the numbers of exotic *Eretmocerus* individuals dramatically increased, with this upward trend continuing through the last sample date in October. A random sample of 12 female *Eretmocerus* collected from all ten the sample sites were tested using RAPD-PCR. Genetic testing of the parasitoids indicated 71% were the exotic *Eretmocerus sp.* (M95012 - Pakistan) and 29 % *Eretmocerus tejanus*. From this data it appears that the new exotic species of *Eretmocerus* from Pakistan is well established in the LRGV. We intend to continue monthly monitoring of the changing parasitoid species complex through 1998.

**Investigator's Name(s):** Juli Gould[1], Diane Waldner[1], Nick Colletto[1], Larry Antilla[2], Rick Santangelo[3].

**Affiliation & Location**: [1]USDA-APHIS, Phoenix Plant Protection Center, [2]Arizona Cotton Research and Protection Council, [3]University of Arizona.

**Research and Implementation Area**: Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report**: January 1997-December 1997.

## Release of Exotic Parasitoids for Establishment in Arizona

The USDA silverleaf whitefly biocontrol project has identified several key crops that support the growth of whitefly populations but do not harbor a large fauna of parasitoids. Extensive laboratory and field cage trials have identified parasitoids that perform better than the native *Eretmocerus* on both cole crops and melons. These parasitoids (all *Eretmocerus* species) were the target of introduction efforts in Arizona for 1997. Agricultural crops, while they are an ultimate target of the parasitoids we are attempting to establish, provide harsh environments and are inappropriate for inoculative releases. We felt that release of parasitoids in residential areas nestled among agricultural fields was a better approach.

Home gardeners planted crops that support whitefly populations throughout the year. Parasites were released at 23 sites in Arizona once every three weeks after whitefly nymphs became plentiful. Over 3 million *Eretmocerus* from Pakistan, Israel, and the United Arab Emirates were released. Whenever a release was made, we collected leaves of the different plants containing mature whiteflies. The leaves were placed in emergence canisters, and the number of exotic and native male parasitoids emerging was recorded. Twenty females from each site were mounted on slides to determine which exotic parasites were reproducing at each site.

All three species of *Eretmocerus* exhibited within season reproduction in Arizona. *Eretmocerus* from Pakistan reproduced at 16 sites, *Eretmocerus* from Israel reproduced at 16 sites, and the *Eretmocerus* from the United Arab Emirates was found to reproduce at 17 sites. Research is currently underway to determine a) whether these exotic parasite species are reproducing on ornamental plants in the urban areas and b) how far from the release sites the parasitoids moved within the first season, and c) whether the parasitoids can survive the winter in Arizona.

**Investigator's Name(s):** S.M. Greenberg[1], Walker A. Jones[2], and W.C. Warfield[3].

**Affiliations & Locations:** [1]Joint affiliation: Beneficial Insects Research Unit, USDA-ARS and [2]Texas Agricultural Experiment Station, Weslaco, TX, [3]Beneficial Insects Research Unit, Subtropical Agricultural Research Center, USDA-ARS, Weslaco, TX.

**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** 1997.

## Comparative Evaluation of Host Instar Suitability of *Bemisia argentifolii* (Homoptera: Aleyrodidae) for the Parasitoids *Eretmocerus mundus* and *Encarsia pergandiella* (Hymenoptera: Aphelinidae)

Studies were conducted to compare preference of *B. argentifolii* instars for parasitization by *Encarsia pergandiella* Howard and *Eretmocerus mundus* Mercet under no, two and four instar choice conditions. Host nymphs (35) were exposed separately to two mated females of each species for 3 h. Both parasitoids preferred different host instars for parasitization in no choice and choice treatments. In the no choice treatment, *E. mundus* successfully parasitized the younger host instars, while *E. pergandiella* was more successful parasitizing the older instars. Similar results were observed when parasitoids were provided two instar choices. But the different host instar suitability is less developed than in the no choice situation. When all four instars were provided the highest percentage of parasitization by *E. pergandiella* was on third instars; the lowest on first instars. The number of parasitized first, second, and third instars by *E. mundus* was not significantly different each other but those were significantly higher compared with fourth instar nymphs.

**Investigator's Name(s):** S. M. Greenberg[1], Walker A. Jones[2], and W. C. Warfield[2].

**Affiliations & Locations:** [1]Joint affiliation: Beneficial Insects Research Unit, USDA-ARS and Texas Agricultural Experiment Station, Weslaco, TX; [2]Beneficial Insects Research Unit, Subtropical Agricultural Research Center, USDA-ARS, Weslaco, TX.

**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** 1997.

## Host Instar Suitability of *Bemisia argentifolii* (Homoptera: Aleyrodidae) for the Parasitoid *Encarsia pergandiella* (Hymenoptera: Aphelinidae)

Studies were conducted to assess the influence of first, second, third, and "early" and "late" fourth nymphal instars of *Bemisia argentifolii (Bellows* & Perring) attacked by *Encarsia pergandiella* Howard on host mortality and parasitoid survival, developmental time, distribution of emergence per day, progeny longevity and body length. Host suitability for male production was not examined. About 35 nymphs from each instar per replication were exposed to two mated parasitoid females for 3 h. All instars were accepted as hosts. The highest percentage of parasitized nymphs occurred on third instars (55.0%) and the least on first instars (26.3%). The second, third, and "early" fourth instar hosts resulted in the highest proportion of total host mortality (75.3%) and parasitoid survival (76.1%) compared with that for first and "late" fourth instars. The highest percentage of parasitoid emergence (96.3%) was when third instars were parasitized, and the least when first (69.4%) and "late" fourth (69.9%) instars were attacked. Parasitoids took significantly longer to develop after parasitizing first instars (14.9 d) than after parasitizing the other instars (11.0 - 12.0 d). The shortest period of progeny emergence (2.0 d) was when *E. pergandiella* had parasitized the third instar. The longevity of unfed progeny was significantly longer (2.3 - 3.0 d) for adults emerged from hosts attacked at the third or "early" fourth instars compared with those following parasitization of first (1.47 d), second (1.87 d) or "late" fourth (1.4 d) host instars. When *E. pergandiella* parasitized the first or "late" fourth instars, emerging females were significantly smaller (0.437 - 0.444 mm) compared with those emerged from other instars (0.483 - 0.495 mm). These findings represent a part of a series of studies for improving our knowledge of the biology of *E. pergandiella.*

**Investigator's Name(s):** S. M. Greenberg[1], Walker A. Jones[2], and W. C. Warfield[2].

**Affiliations & Locations:** [1]Joint affiliation: Beneficial Insects Research Unit, USDA-ARS and Texas Agricultural Experiment Station, Weslaco, TX; [2]Beneficial Insects Research Unit, Subtropical Agricultural Research Center, USDA-ARS, Weslaco, TX.

**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report**: 1997.

## Host Instar Suitability of *Bemisia argentifolii* (Homoptera: Aleyrodidae) for the Parasitoid *Eretmocerus mundus* (Hymenoptera: Aphelinidae)

Studies were conducted to assess the influence of nymphal instars of *Bemisia argentifolii* (Bellows and Perring) attacked by *Eretmocerus mundus* Mercet on host mortality, parasitoid survival, development time, and progeny longevity. *Eretmocerus mundus* parasitized all nymphal host instars. The highest percentage of parasitized nymphs was on the second instars (66.4%) and the least on the fourth (red-eyed nymph) instars (8.6%). The second instars exhibited the highest proportion of host mortality and parasitoid survival. The greatest rate of parasitoid emergence (93.8 %) was when the second instar hosts was parasitized, and the lowest emergence (35.7%) was on fourth instars. Parasitoids development was longest when parasitized in the first instars (16.3 days). The longevity of unfed female progeny emerged from host attacked at the second instars was 2.6 days compared with 1.5 days from fourth instars.

**Investigator's Name(s):** James Hagler.

**Affiliation & Location:** USDA-ARS, Western Cotton Research Laboratory, Phoenix, AZ.

**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** April 1997 - December 1997.

## A Laboratory Study of the Prey Preference of Five Predator Species on the Various Whitefly Life Stages

A laboratory study was conducted that evaluated the feeding behavior of five insect predators when exposed to the various life stages of whitefly. The predators examined included: *Collops vittatus, Geocoris punctipes, Orius tristicolor, Drapetis sp.,* and *Hippodamia convergens*. The behaviors monitored included: feeding (eggs, nymphs, and adults), resting, grooming, walking, and probing. Based on the number of prey consumed, adult whiteflies were preferred over eggs and nymphs by every predator species examined.

**Investigator's Name(s):** James Hagler[1], Glen Jackson[3], Juli Gould[2], & Matt Ciomperlik[2].

**Affiliation & Location:** [1]USDA-ARS, Western Cotton Research Laboratory, Phoenix, AZ; [2]USDA-APHIS, Phoenix, AZ; & [3]USDA-APHIS-PPQ, Mission Biological Control Center, Mission, TX.

**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** March 1997 - December 1997.

## A Simple Protein Marking ELISA to Quantify Parasitoid Dispersal

Laboratory and field studies were conducted to evaluate the efficacy of marking whitefly parasitoids with a protein prior to enzyme-linked immunosorbent assay (ELISA). Data indicate that this marking technique is superior to conventional marking techniques.

In the laboratory, adult *Eretmocerus mundus* and *Encarsia formosa* were marked with the readily available mammal protein, rabbit immunoglobulin G (IgG), by three different application methods. Adult parasitoids were marked internally by feeding them a honey solution "spiked" with rabbit protein and externally by contact exposure or topical mist. Marked individuals were then assayed using a sandwich ELISA for the presence of the protein marker using an antibody specific to rabbit IgG (antirabbit IgG developed in goat). Data indicate that the IgG marker was retained throughout the entire adult life span in almost (>95.0%) every individual parasitoid assayed, regardless of the application method used.

In the field, adult *Eretmocerus* from The United Arab Emirates were internally marked by feeding them a honey solution spiked with rabbit protein. The marked parasitoids were then released into the center of a cotton field that was surrounded by cantaloupe and okra. Parasitoids were recaptured every 2 hours for 36 hours after release using passive suction vacuum traps (24 traps total) located in the cotton, cantaloupe and okra fields. Data indicate that the marking technique was very effective for monitoring parasitoid dispersal. Furthermore, the passive suction fan traps were very effective at recapturing the released parasitoids.

**Investigator's Name(s):** James Hagler & Steve Naranjo.

**Affiliation & Location:** USDA-ARS, Western Cotton Research Laboratory, Phoenix, AZ.

**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** June 1996 - December 1997.

## Feeding Behavior of Whitefly Predators Exposed to Insect Growth Regulators and Conventional Insecticides

A field study was conducted to evaluate the sub-lethal effects of insect growth regulators (buprofezin and pyriproxyfen) and conventional insecticides on predator foraging behavior. Management systems included two whitefly growth regulators, a rotation of conventional insecticides, and an untreated control. All insecticides were applied according to recommended thresholds. Gut contents of over 33,000 predators representing over 25 genera were examined for whitefly prey remains using a whitefly monoclonal antibody-based ELISA. These data are currently being analyzed and summarized.

**Investigator's Name(s):** Larry J. Heilmann.

**Affiliation & Location:** USDA-ARS, Biosciences Research Laboratory, Fargo, North Dakota 58105.

**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** 1997.

## Satellite DNAs as Identification Probes for *Encarsia* and *Eretmocerus* Wasps

The quick, precise identification of biological control species is necessary for successful release programs. This is particularly important for parasitic wasp species where it is necessary to determine whether a given exotic strain is reproducing in its new environment, and to be able to follow the strain in relation to other strains and any native strains. Because of the very small size of most parasitic wasps, physical methods of identification are tedious and difficult. Newer molecular methods using PCR are highly accurate but expensive and time consuming. We have been investigating the use of highly repetitive satellite DNAs as species-specific molecular markers. From *Encarsia formosa*, we have isolated a short 33 bp sequence that is detectable only in Egyptian and Greek strains. From *Eretmocerus mundus*, we have isolated two satellite sequences of 172 and 176 bp. They are detectable only in old world species/strains of *Eretmocerus* and not in North American species/strains. We are also attempting to isolate satellite DNAs that would distinguish between *Eretmocerus* from Pakistan and the United Arab Emirates. Eventually, we plan to use these sequences as probes for quickblot hybridization reactions with squashes of individual single insects. We are also investigating microsatellite sequences and the ribosomal RNA genes from both genera.

**Investigator's Name(s):** K.A. Hoelmer.

**Affiliation & Location:** USDA, APHIS, Phoenix Plant Methods Center, Brawley, CA.

**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** March 1997 to June 1997.

## Comparative Field Cage Evaluations of Top-Performing Introduced Parasitoids in Desert Cantaloupes

Evaluations of non-indigenous parasitoids of *Bemisia* have been conducted to identify effective new species or populations to establish against whiteflies in key crops grown in desert valleys of California and Arizona. Tests conducted during the past several years evaluated numerous introduced cultures comprising 8 species of *Eretmocerus* and 7 species of *Encarsia* from 13 different countries. However, because these cultures were available for study at different times, many of the best performers identified in previous studies were not evaluated against each other concurrently. This test compared each of the best candidate species to date on cantaloupe, a key crop for improving biological control in desert regions with year-round production of whitefly hosts.

Field-cage evaluations in cantaloupes at Brawley were conducted in the spring and summer of 1997. Cultures evaluated included *Eretmocerus mundus* M92014 (Spain) and M94120 (Israel), *Eretmocerus* M92019 (India; this culture is now known to have been a mixture of *E. mundus* and *E. sp.* ex Pakistan), *Eretmocerus sp.* M95012 (Pakistan), *Eretmocerus sp.* M95104 (United Arab Emirates), *Eretmocerus sp.* M96076 (Ethiopea) and the southwestern desert native *Eretmocerus eremicus*. The USDA, APHIS Mission Biological Control Center in Mission, TX, the California Department of Food & Agriculture, Biological Control Program in Sacramento and Novartis BCM/Bunting U.S.A. provided parasites from their cultures for these studies.

Releases of parasitoids were made into 6x6x6 ft field cages (4 replicate cages per species/culture) containing cantaloupes. Each cage contained two rows of 3 to 4 plants per row grown on trellises. Inoculations of equal numbers of whitefly adults were made into each cage. When 2nd & 3rd instar whitefly nymphs were present, 100 female parasitoids were released into each cage, accompanied by males for mating, and the development of their progeny was monitored. Pre-release and $F_1$ progeny voucher specimens were collected from each sample to verify the identity of each culture and any contaminating species present. All leaves with parasitized whiteflies were collected to record the production of $F_1$ progeny by each species or population, which was determined by counting the number of larval, pupal and emerged $F_1$ generation progeny on foliage in each cage.

Cultures M95104 from the United Arab Emirates and M96076 from Ethiopia produced the greatest numbers of $F_1$ progeny per female. Mean production by each of these two cultures was 66 $F_1$ progeny. *Eretmocerus mundus* cultures M92014 (Spain) and M94120 (Israel) were next most productive, with 55 and 51 progeny/female respectively. Native *Eretmocerus eremicus* and M95012 from Pakistan produced less than half the progeny of the two top performing cultures. The mixed culture (M92019, India) was intermediate to other *Eret. mundus* cultures and the *Eret.* from Pakistan. The best-performing cultures in these desert southwest trials were those from the most similar climatic regions, the Arabian peninsula and nearby arid northeastern Africa. *Eretmocerus eremicus*, which is indigenous to arid southwestern North America, readily attacks *Bemisia* but may be better adapted as a parasitoid of native *Trialeurodes* which occur in the same habitats as the introduced *Bemisia*.

**Investigator's Name(s):** Kim Hoelmer[1], James Hagler[2] and C. Glen Jackson[2].

**Affiliation & Location:** USDA, APHIS, Phoenix Plant Methods Center, Brawley, CA[1] & USDA, ARS, Western Cotton Research Laboratory, Phoenix, AZ[2].

**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report**: January 1997 to December 1997.

## Continuing Studies of *Semidalis sp.*, a Native Predator of *Bemisia* in Desert AZ and CA

Populations of a dustywing, *Semidalis sp.* (Neuroptera: Coniopterygidae), were previously reported to increase dramatically in response to population increases of *Bemisia* on ornamental shrubs and trees in urban areas of Imperial County, CA and Yuma, AZ. They have also been found associated with *Bemisia* in the Phoenix area. Larval and adult *Semidalis* have proven to be voracious predators of whitefly eggs and nymphs. Parasitized whiteflies are also attacked and consumed.

Surveys of ornamental and tree hosts in urban areas of Imperial Valley are in progress to record population changes of *Semidalis* over a period of several years. Pupae are collected in these surveys and examined in the lab to determine levels of successful emergence and mortality from parasitism and predation throughout the year. We have reared three species of parasitic Hymenoptera from pupal *Semidalis* in the Imperial Valley in survey collections. One species of primary parasitoid of *Semidalis* has been identified as *Dendrocerus conwentziae* (Megaspilidae). Two species of hyperparasitic chalcidoid wasps attack pupal *Dendrocerus* (Aphelinidae: *Marietta* sp. and an unidentified Encyrtidae sp.)

Observations of the feeding behavior and development of *Semidalis* larvae were continued at Brawley. In the laboratory, larvae (n=26) fed for 8 - 13 days after hatching (mean 10.3 d) and passed through 3 (58%) or 4 (42%) stadia prior to pupation. During their development from eggs, larvae consumed from 1000 to 2323 whitefly eggs (mean 1738.7) prior to pupating. Pupation lasted from 8-14 days (mean 10.9 d). Further feeding studies with different stages of whitefly nymphs as prey are planned.

Starved individual adult dustywings (n=27) were given *Bemisia* mixed eggs and nymphs on cotton leaves in the laboratory in Phoenix and their behavior was observed in detail for one-hour periods. Recorded activities of both sexes included resting (36%), walking (21%), grooming (19%) and feeding (22%), with less than 2% of time spent in other activities. Males consumed an average of 8.7 eggs and 6.8 nymphs in an hour while females ate 8.4 eggs and 11.6 nymphs per hour. Mean consumption time per prey item was 28.4 sec for eggs and 61.0 sec per nymph. This was in accord with previous choice tests conducted in Brawley, in which adults accepted either eggs or young instars, whereas larvae demonstrated a strong preference for young whitefly nymphs over eggs.

Preliminary gut content assays of *Semidalis* larvae and adults showed that *Bemisia* egg antigens were detectable in lab-reared individuals. Those results were consistent with observed whitefly stage preferences of larvae and adults. Collections of field populations of adult and larval *Semidalis* are currently being analyzed.

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**Research & Implementation Area**: Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** January 1997 - November 1997.

## Establishment of Introduced *Eretmocerus* species in Imperial Valley, CA

To date, many different geographic populations of parasitoids have been released in the Imperial Valley. Some of the cultures found to be effective in field evaluations against whiteflies on desert crops have been released in very large numbers. Five different non-indigenous *Eretmocerus* species have been released in numbers exceeding 250,000. Several geographic collections of *Eretmocerus mundus* from Israel and Spain and two distinct unnamed *Eretmocerus* species originating in Pakistan (M95012) and the United Arab Emirates (M95104) have been released in numbers exceeding 5 million individuals. During 1997 alone, approximately 19 million *Eretmocerus* M95104 were released, mostly for demonstration projects in commercial melons and cotton (reported separately). Release sites were widespread and included commercial crops, alfalfa acreage in the Salton Sea National Wildlife Refuge and numerous urban and rural residential sites throughout the Imperial Valley.

In 1996, recoveries of exotic *Eretmocerus* species were made at a number of widely separated urban and agricultural sites in Imperial Valley. The location and timing of these recoveries indicated to us that either successful overwintering or dispersal of several miles, or both, had occurred at these sites. However, numerous other sites that were sampled produced only specimens of the native *Eretmocerus eremicus*, indicating that establishment of introduced species was not yet widespread.

During 1997, we have continued to sample widely from many urban, desert and agricultural sites. Early-season samples of urban ornamentals collected as early as March and April included overwintering exotic *Eretmocerus*. Introduced *Eretmocerus* were also recovered in late spring from commercial melon fields located several miles from the nearest 1996 or 1997 release sites. During the fall months of 1997, numerous collections from urban and rural sites were made which included exotic *Eretmocerus* species. Many of these sites were locations at least several miles from the nearest release or recovery site this year or in previous years. Large numbers of individual *Eretmocerus* were reared from these sites; the proportion of exotics among the total *Eretmocerus* reared was frequently 10 to 20% and was as high as 50% at several sites. Although many of these specimens must still be examined to make species identifications, *Eretmocerus* M95104 (UAE) predominate among specimens identified thus far.

Managed refuge plantings consisting of okra, basil, collards and roselle were monitored throughout 1997. During this period, *Eretmocerus mundus* from Israel and *Eretmocerus* sp. M95104 from UAE were released at each site to promote local establishment. The proportion of exotic vs. native *Eretmocerus* in samples from these refuges appeared to be higher than in 1996 on okra (38% vs. 15%) and collard (83% vs. 56%), reflecting similar trends seen in samples of urban ornamentals.

Recoveries of introduced *Eretmocerus* in Imperial Valley in 1997 were made at a greater number of discrete locations and in larger numbers and proportions than in 1996. These recoveries are further evidence that establishment of one or more introduced *Eretmocerus* species is occurring.

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**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** 1997.

## Comparative Evaluation of Host Instar Suitability of *Bemisia argentifolii* (Homoptera: Aleyrodidae) for the Parasitoids *Eretmocerus mundus* and *Encarsia pergandiella* (Hymenoptera: Aphelinidae)

Studies were conducted to compare preference of *B. argentifolii* instars for parasitization by *Encarsia pergandiella* Howard and *Eretmocerus mundus* Mercet under no, two and four instar choice conditions. Host nymphs (35) were exposed separately to two mated females of each species for 3 h. Both parasitoids preferred different host instars for parasitization in no choice and choice treatments. In the no choice treatment *E. mundus* successfully parasitized the younger host instars, while *E. pergandiella* was more successful parasitizing the older instars. Similar results were observed when parasitoids were provided two instar choices. But the different host instar suitability is less developed than in the no choice situation. When all four instars were provided the highest percentage of parasitization by *E. pergandiella* was on third instars; the lowest on first instars. The number of parasitized first, second, and third instars by *E. mundus* was not significantly different each other but those were significantly higher compared with fourth instar nymphs.

**Investigator's Name(s):** Velia Leija-Chapman, Matthew Ciomperlik, Lloyd Wendel.

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**Research and Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** Spring and Fall 1996.

## Biology and Predation of *Serangium parcesetosum* (Coleoptera: Coccinellidae) on *Bemisia tabaci* (Gennadius) (biotype B) (Homoptera: Aleyrodidae)

*Serangium parcesetosum* (= *Catana parcesetosa*) is a coccinellid predator that has demonstrated potential for the biological control of Sweetpotato whitefly (SPWF), *Bemisia tabaci*, biotype B (Homoptera: Aleyrodidae). This coccinellid was originally collected from India and described by Sicard (1929) where it became an important biological control agent of the citrus whitefly, *Dialeurodes citri* Ashmead. As a result of the success of that biological control program, this coccinellid has also been found to be of significant importance to the suppression of various whitefly populations. This coccinellid is predaceous in both immature and adult stages. Because of the limited biological information on this species, laboratory studies on its biology and predation rates are essential in order to evaluate its potential as a biological control agent of *B. tabaci.*

Adult coccinellids were collected from greenhouse cultures and were held as a group in small laboratory cultures in plexiglass cages on eggplant infested with SPWF. Male and female pairs were gathered from the laboratory cultures when mating was observed. The male/female pairs were isolated into individual ventilated 9 cm. plastic petri dishes that contained single hibiscus leaves infested with an abundant supply of SPWF immatures. The mated pairs were observed hourly to determine if eggs had been oviposited by the adult female. After each egg was produced, the length was measured and then the egg was placed into another ventilated 9 cm. plastic petri dish with a hibiscus leaf that held an abundant supply of immature SPWF. Observations were made every 24 hours to determine the development stage of the developing immature. *Serangium parcesetosum* eggs took 5.0 days to hatch to the first instar. The 1st instar larvae molted to the 2nd instar in about 1.4 days, and 2nd instars molted to third instar in 1.5 days. Third instar larvae molted into 4th in about 1.4 days, and it took about 2.2 days for the 4th instar to pupate. Pupae developed into adults in about 3.9 days. The mean life-cycle of *Serangium parcesetosum* from egg to adult was determined to be 15.4 days.

Predation rates were also studied. Each individual larvae was placed in 5 cm. plastic petri dishes with leaf discs having a 1 cm. radius. The leaf discs were cut from *Hibiscus rosasinensis L.* leaves. Each disc contained the various whitefly instars (i.e. eggs, 1sts, 2nds, 3rds and 4ths). Prior to the introduction of the larval instar, counts were made for each individual disc and recorded. Observations were made every 24 hours to determine host stage preference and counts were made to determine how many SPWF instars were consumed.

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**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Date Covered:** 1997.

## Efficacy of *Beauveria bassiana*, Entomopathogen of *Bemisia argentifolii* Nymphs on Hibiscus under Two Humidity Regimes

*Beauvaria bassiana* is a fungal pathogen that attacks many types of insects, including *Bemisia argentifolii* Bellows & Perring. Susceptibility of an insect species depends on the particular strain of *B. bassiana*, as well as environmental conditions. Growth and sporulation are favored by warm temperatures and particularly, by high relative humidity. Thus, the fungus might be expected to work well in propagation greenhouses where RH are normally maintained >90% by frequent misting. We conducted a screenhouse trial at Southwest Florida Research and Education Center in Immokalee simulating these conditions with overhead misters as an initial test of practical feasibility. *Beauveria bassiana*: Mycotrol ES (Botaniguard, water-based formulation), was tested in the experiment with water as control. The rates (concentrations) used were 2.5 and 1.25 ml material per liter of water, equivalent to the recommended 0.5 and 1.0 quart per 100 gallon water. Leaves bearing second instar whitefly nymphs were sprayed to runoff using a hand sprayer and allowed to dry for 2 h. Mist was applied hourly the first 24 h for 1 minute from 0700 to 1900 hours. After 24 h in each treatment were divided into two groups, one of which was left under the misters (RH > 95%) and the other irrigated by drip (65-75% RH during the daytime, and >90% RH at night). Hibiscus leaves were removed from the plants 10 days after treatment and counted as dead or alive under a stereoscopic microscope. Percentage mortality was transformed to arc sine (arsin (x/100)) for analysis.

High mortality of whitefly nymphs was observed from all treatments of *B. bassiana*, with the higher concentration causing greater mortality. However, there was no significant effect between misting and not misting 24 h after treatment ($P < 0.05$). Percentage mortality of whitefly nymphs under 10-d high humidity was 91.6% at the high rate, 80.1% at the low rate, and 4.2% for untreated control. With only 24 h of misting mortality was 90.1% at the high rate, 76.7% at the low rate, and 3.3% on untreated plants. Thus, it appeared that the 24-h misting period was sufficient to allow for germination of the fungal conidia on whitefly nymphs and that high RH level was not necessary for subsequent development of fungal infection to proceed satisfactorily.

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**Research & Implementation Area**: Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** April 1997 - October 1997.

## Conservation of *Bemisia* Natural Enemies in Integrated Whitefly Management Systems

As part of a continuing study to evaluate and demonstrate strategies for *Bemisia* management we compared natural enemy conservation in untreated plots and in plots under three different insecticide regimes (buprofezin followed by pyriproxyfen, pyriproxyfen followed by buprofezin, and a rotation of conventional materials). Each treatment was replicated 4 times in 0.27 hectare plots. Whitefly populations were monitored weekly and all insecticides were applied according to recommended action thresholds. A split-plot design was created in late July when half of all plots (except the conventional) were sprayed once to control *Lygus hesperus*. Results for whitefly control and insecticide use are presented in Ellsworth et al., Section F, this volume).

Weekly sweepnet samples were used to estimate the abundance of arthropod predators, and leaf samples (7th mainstem node) were used to estimate the abundance and activity of native whitefly parasitoids. We monitored the abundance of approximately 30 predator species.

Preliminary results indicate that *Eretmocerus eremicus* and *Encarsia meritoria* were present throughout the season, although the former species was dominant, comprising about 80% of all parasitoids collected. Rates of parasitism began low, generally peaked around mid-August (20-30%) and then declined. Parasitism averaged about 8.4% over the whole experimental area for the season. Host and parasitoid densities differed significantly among insecticide regimes on most post-treatment dates and were consistently highest for the untreated control and lowest for plots treated with pyriproxyfen. Percentage parasitism differed among treatments on 3 of 6 post-treatment dates and was generally highest for pyriproxyfen plots (2-30%) and lowest for buprofezin and untreated control plots (2-11%). Spraying for *Lygus* in late-July had little effect on host and parasitoid abundance or percentage parasitism.

For preliminary analysis of predator abundance, we pooled species into three groups: beetles, heteroptera and spiders. Spraying for *Lygus* in late-July generally depressed predator populations for the remainder of the season. Average densities of predaceous beetles were low (< 2 per 50 sweeps) over the whole season and few differences were observed due to insecticide regimes. The remaining predator groups were affected on the majority of post-treatment sampling dates. Heteropteran abundance was consistently highest in untreated or pyriproxyfen-treated plots and lowest in conventional insecticide plots. The same was generally true for spider abundance, although there were fewer dates on which significant differences were detected and overall densities were low (< 3.5 per 50 sweeps).

These preliminary results corroborate findings from large plot (1.6 ha) studies in 1996 and suggest that natural enemies are conserved in areas treated with insect growth regulators compared with fields receiving rotations of conventional insecticides. Further, more detailed analyses on individual predator species are underway as are studies to measure predator activity through gut content assays (Hagler and Naranjo, Section D, this volume).

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**Research & Implementation Area**: Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report**: Fall 1996 - Fall 1997.

## Recovery and releases of Parasites for Biological Control of *Bemisia* sp. in the San Joaquin Valley, California

The USDA-APHIS PPQ and the California Department of Food & Agriculture's Biological Control Program have been evaluating, releasing and monitoring parasites of *Bemisia* sp. in southern California since 1993. Field and laboratory studies have measured the fecundity and preference of female parasites for different host plants. Field releases of small numbers of a wide range of new species/populations in Bakersfield, California were conducted to determine the overwintering survivorship in central California under field conditions. Based on the results of these studies large numbers of the three most promising candidates were released in 1996 and 1997, primarily into agricultural settings in Kern, Kings, Tulare, and Fresno Counties (central California). In 1996 a total of 168,360 M92014 (*Eretmocerus mundus*), 123,745 M95012 (*Eretmocerus* from Pakistan), and 18,521 M95104 (*Eretmocerus* from United Arab Emirates) were released over Kern, Kings, and Tulare Counties. Parasites were released as adults directly onto *Bemisia* infested foliage of cotton, citrus, or weedy plants (e.g. Sonchus, cockle burr, spurge), or as pupae associated with potted hibiscus plants. In 1997 a total of approximately 6 million M95104 were released into Kern, Tulare, and Fresno Counties. Most of these were released into citrus in fall as a part of a new project to colonize parasites in citrus bordering cotton with high *Bemisia* infestations. Over the same time a total of 371,000 M95012 were released into a mix of agricultural and home sites in Kern and Fresno Counties.

Exotic *Eretmocerus* have been recovered from 6 locations two years following release, from two locations one year following releases and from five sites where releases were made within 1997. One recovery was made from a cotton field located at least 2 miles from the nearest release site where releases have been made since 1996. Based on genetically unique DNA patterns, the *Eretmocerus* M92014 has been repeatedly recovered at one site over a two year period, accounting for 25 to 56 % of the males recovered (the remainder being natives). We recovered M92014 and M95012 from citrus 5 months after releases and M92014 from nearby Sonchus, 9 months later. We have yet to determine the species/population for the remaining sites. We also recovered for the first time *Eretmocerus tejanus* just south of Bakersfield where augmentative releases of this species were made into cotton in 1994 (Heinz, unpublished data). These parasites are native to southern Texas.

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**Research and Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** 1997.

## Effects of Entomopathogenic Fungi on *Serangium parcesetosum* (Coleoptera: Coccinellidae), an Important Predator of Whiteflies

We performed laboratory evaluations on the lethal and non-lethal effects of the entomopathogenic fungi *Beauveria bassiana* (Balsamo) Vuillemin (strain GHA) and *Paecilomyces fumosoroseus* (Wize) Brown & Smith (strain 612) against *Serangium parcesetosum* Sicard, a non-target cocinellid predator of aleyrodid whiteflies. Using 'high' (~1000 conidia $mm^{-2}$), 'medium' (~200 $mm^{-2}$) and 'low' dosages (~40 $mm^{-2}$) of both fungi, we measured lethal (induced mortality) and non-lethal effects on predator body weights, the duration of larval and pupal stages, and predation rates prior to pupation. We also tested if the ingestion of whitefly contaminated with *B. bassiana* affected predator survivorship in three tests: 1) *S. parcesetosum* larvae were fed contaminated whiteflies for a 10-d period; 2) predators were fed one time only prey contaminated 24-, 48-, 72-, or 96-h previously; 3) conidia were washed off the leaves and prey cuticles prior to exposure to the prey (to simulate degradation of conidia in the field). *S. parcesetosum* produced significantly lower survivorship when sprayed with *B. bassiana* than with *P. fumosoroseus*. However, survivorship was not affected by the dosage rates for each pathogen. Survivorship curves for the *P. fumosoroseus* treatment also did not differ significantly from blank and carrier controls. Mean larval duration was longest in *S. parcesetosum* sprayed at the medium and high dosages of *B. bassiana* (~22.5 d), intermediate for the low dosage of *B. bassiana* (~20 d), and lowest for the blank and carrier controls and the *P. fumosoroseus* treatments (~18 d). The pupal stages averaged 6.6 - 8.0 d. Mean adult body weights ranged from 0.97 mg (*B. bassiana* low dosage) to 1.54 mg (*P. fumosoroseus* medium dosage), but were not significantly different. Analysis of cumulative predation showed that predators sprayed with *P. fumosoroseus* consumed prey at a rate similar to that of the controls (~130 prey daily per predator), which was significantly higher than predators sprayed with *B. bassiana* (~60 prey daily per predator). Again, dosage was not a significant factor. Feeding on *B. bassiana*-contaminated prey caused ~90% mortality in *S. parcesetosum* immatures, as compared to only ~23% in the controls. Prey contaminated 24-, 48-, 72-, and 96-h previously induced (10-d Abbott corrected) mortalities of 92.5, 71.4, 71.4, and 44.4%, respectively. Washing conidia off the leaves and the cuticle of whiteflies did not result in lowered mortality of the predator relative to the other treatments. Because *P. fumosoroseus* did not induce significant mortality on *S. parcesetosum*, we believe they may be compatible control agents in an integrated pest management program of whiteflies. However, the use of *B. bassiana* in conjunction with *S. parcesetosum* may be problematic. Continuous and 1-time exposures resulted in similar mortalities. Neither was mortality dependent on the age of the predator when exposed to *B. bassiana*, nor the age of the fungal infection in the prey. *S. parcesetosum* was highly susceptible to both direct sprays of *B. bassiana*, and to predation on contaminated prey. Effective use of these agents together may require the selection of less toxic strains of *B. bassiana*, or timing the application of the pathogen so as to minimize its effect on *S. parcesetosum*.

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**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** November 1995 to August 1997.

## Field Cage Evaluations of Non-indigenous Parasitoids in Desert Crops

Five species/strains of autoparasitic *Encarsia* (Hymenoptera: Aphelinidae) have been evaluated on several plant species in Imperial Valley. These studies were done in tandem with those conducted by Kim Hoelmer (USDA-APHIS), who evaluated species of *Eretmocerus* and uniparental *Encarsia.* All parasitoid species/strains except one were provided by the Mission Biological Control Center, USDA-APHIS, Mission, TX. Accession M92018 was provide by Greg Simmons, USDA-APHIS, Brawley, CA.

Field cages, (2x1.5x2 m, 52x52 mesh Lumite screen) were set up to house transplanted greenhouse grown seedlings. Three cages were prepared as replicates for each species/strain evaluated, as well as for a control [i.e., whitefly only]. Whiteflies were introduced into each cage (approx. 200 females per cage for broccoli and cotton, and 80 on cantaloupe) 9-14 days following transplanting. When early fourth instar whiteflies were present, 50 female parasitoids were released into each cage with 10 males. Fourteen and 21 days later, when early stage parasitoid pupae were present, 20 additional females along with 2-5 males were introduced into each cage in order to de-synchronize the parasitoid generations within each cage to facilitate continual male and female production. Assessment of F1 production was accomplished by collecting half leaf samples when the F1 generation began to emerge. Species/strains evaluated included: *Encarsia transvena* [M93003 (Spain), M94041 (Thailand), M94047 (Malaysia), M95107 (Multan, Pakistan)] and Encarsia sp. M92018 (India). Overall, M93003 was the most consistent performing accession tested in this group. However, M95107 did exceptionally well on cotton during the hot summer months. In 1997, M95107 was assessed a second time in cotton to validate 1996 results.

| Crop | Period | Accession # | F1 Fecundity/female | Range |
|---|---|---|---|---|
| Broccoli | Fall 1995 | M93003 | 12.9 | 10.3-15.5 |
| | | M94041 | 4.1 | 2.7-4.8 |
| | | M94047 | 6.1 | 4.2-7.5 |
| Cantaloupe | Spr. 1996 | M93003 | 17.6 | 10.6-24.7 |
| | | M94041 | 14.8 | 9.2-22.7 |
| | | M94047 | 1.6 | 0.3-2.4 |
| Cotton | Sum. 1996 | M93003 | 17.7 | 9.0-40.3 |
| | | M95107 | 78.5 | 20.3-185.2 |
| | | M92018 | 9.9 | 6.9-8.1 |
| Broccoli | Fall 1996 | M93003 | 12.8 | 9.8-15.6 |
| | | M95107 | 5.0 | 2.0-11.4 |
| | | M92018 | 1.1 | .3-1.7 |
| Cantaloupe | Spr. 1997 | M95107 | 14.3 | 10.0-21.0 |
| | | M92018 | 7.0 | 6.0-7.9 |
| Cotton | Sum. 1997 | M95107 | 159.2 | 36.3-253.2 |

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**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** 1994 -1997.

## Annual Plants for Natural Enemy Refuges in Imperial Valley, CA

Refuge plant systems for the conservation of whitefly natural enemies exist within a continually changing environment. Habitat utilization characteristics of indigenous natural enemy species may be changing, and introduced natural enemies are anticipated to attack whitefly on whitefly host plants that previously represented enemy-free space for a portion of the silverleaf whitefly population.

Sunflower (*Helianthus annuus*) and collards (*Brassica oleracea*) have been investigated extensively in Imperial Valley. Although native *Eretmocerus* do overwinter on collard and readily move to adjacent crop plants, they do not parasitize enough of the whitefly population on collards to sufficiently build their own numbers for controlling whitefly on collards and adjacent crops. Sunflower provides habitat for whitefly parasitoids thereby preventing their localized extinction. However, because sunflower has a short life cycle, and utilization of sunflower as a host by whitefly is very unpredictable, it has not been a reliable producer of large numbers of native parasitoids necessary for a refuge to be used as a means of within-field whitefly control.

Other annual plant species that have been integrated into field refuge plantings and home gardens for the establishment of exotic natural enemy species, and for general monitoring of parasitoid and whitefly activity include: okra (*Hibiscus esculentus*), sweet basil (*Ocimum basilicum*), roselle(*Hibiscus sabdariffa* cv. *sabdariffa*), kenaf (*Hibiscus cannabinus*), broad bean (*Vicia faba*) and mustard (*Brassica Juncea*). These selections originated from observations in home gardens and covercrop field plantings. Okra grows during the hot months of the year. When seed pods are not removed, it goes through a transitional phase in mid-summer much like cotton, in which vegetative growth is slight and seed pod maturation takes place. By August, okra begins to produce new vegetative growth. It is very attractive to the silverleaf whitefly, and parasitism by *Eretmocerus* species and *Encarsia transvena* (Pakistan strain) is common. Sweet basil grows well much of the year. Whiteflies typically attain low to moderate densities on basil. Roselle's growth is limited to the hottest months of the year, attaining considerable size and lush growth by August. Whitefly densities on roselle are usually very low. Because of its extra floral nectaries and general attractiveness to a wide range of natural enemies, it can be of value at a time when many other plant species have difficulty surviving the high August temperatures. Kenaf is more attractive than roselle to the silverleaf whitefly from July through September, and high levels of parasitism are often observed on kenaf. Because it can grow into a stout, highly fibrous plant, kenaf can be difficult to manage and dispose of at the end of the season. Broad bean can be highly attractive (sometimes overly attractive) to whitefly when grown in the summer. Presently it is being assessed as a potential refuge plant during the winter months. Broad leaf mustard is currently under evaluation as well. It was found lightly to moderately infested with whitefly in the spring months in home gardens and whitefly were found to be extensively parasitized by *Eretmocerus*. Chick pea (*Cicer arietinum*), lab (*Dolichos lablab*), and six varieties of soybean (*Glycine max*) were evaluated within small field plots for their potential as winter refuge plants, however, plant growth and/or whitefly relationships were found to be unsuitable for their further consideration. In that same study seven sunflower cultivars were studied as well. Cultivars with greater utility than the confectionery and long season oil seed cultivars presently in use were not found. Broccoli grown past harvest has been found to be a versatile alternative to growing collard in home gardens where *Encarsia transvena* parasitism is being encouraged. Well established (i.e., 6 months old) broccoli can survive the hot summer temperatures and resume extensive regrowth in October.

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**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates covered by the report:** 1994 -1997.

## Perennial Plants for Natural Enemy Refuges in Imperial Valley, CA

Over 30 plant species have been screened in small field plots for their potential as natural enemy refuge plants. This included low water use landscape plants and native southwestern desert or near-desert flora. Few landscape plant species have been found to contain the appropriate traits for such use. Lavatera (*Lavatera thuringiaca*) and rue (*Ruta graveolens*) were planted into an eight bed strip at two field sites after showing promise in the small plot study. However, many died as a result of several factors including an intense mealybug infestation coupled with high summer temperatures. Interestingly, native *Hibiscus californica* has shown some potential as a summer/fall refuge plant species. It is native to relatively wet areas of central California, however it has grown well from late spring through mid-fall in an Imperial Valley field plot under moderate watering conditions. By late fall, all above ground plant material dies. Purple potato vine (*Solanum rantonnetii*) harbors considerable numbers of whitefly that are well parasitized, however, its compatibility with Imperial Valley's climate and soil characteristics is questionable.

Several desert plant candidates were selected by inspecting plants at botanical gardens in California and Arizona. To date, chuparosa (*Justicia californicus*), *Tecoma stans stans* and *Ruellia peninsularis* show promise in the greater landscape for providing parasitoid source populations. Chuparosa is a dense, unstructured shrub growing to 4 ft in height. *Tecoma stans stans* is a large shrub growing to a height of 12 feet, thereby making it useful as a windbreak as well. *Ruellia peninsularis* is a small to medium size shrub growing to 5 feet in height. Whitefly densities on these plants are typically low, however they can accumulate when migrating whitefly densities are high. These plants are predominantly late summer and fall whitefly host plants, therefore they are not year-long providers of whitefly parasitoids. Compared to *T. stans stans* and *R. peninsularis*, chuparosa is a whitefly host over a greater portion of the year and is the most likely candidate to have some role in carrying parasite populations through the winter, albeit in low densities. Whitefly predation on these plants by various predators is typically very high.

Most perennial plant species require 18 months or more before they are well established. Therefore, they must be planted for a lengthy period of time before they can be sampled and evaluated. Of the plants listed above, another year of study is needed to confirm patterns of parasitoid and whitefly abundance. No whitefly host plants have been found that can be recommended for use outside of managed field areas. All of these plants can make attractive yard plants.

Plants screened:

**Acanthaceae:** chuparosa (*Justicia Californicus*), Brazilian plume (*Justicia carnea*), red *justicia (Justicia ovata*), Mexican honeysuckle (*Justicia spicegera*), Brazilian plume (*Justicia carnea*), *Ruellia Californica*, *Ruellia peninsularis*; **Bignoniaceae:** *Tecoma stans stans*; **Asteraceae:** purple coneflower (*Echinacea purpurea*), gloriosa daisy (*Rudbeckia hirta*), mule fat (*Baccharis viminea*); **Cucurbitacae:** wild gourd (*Cucurbita foetidissima*), coyote melon (*Curcurbita palmata*); **Euphorbiaceae:** spurge (*Euphorbia xantii*); **Malvaceae:** Tara's choice (*Anisodontea* sp.), California hibiscus (*Hibiscus californica*), tree mallow (*Lavatera bicolor*), lavatera (*Lavatera thuringiaca*), hollyhock (*Athaea rosea*); **Rutacea:** rue (*Ruta graveolens*); **Solanaceae:** jimson weed (*Datura meteloides* & *Datura discolor* [an annual sp.]), purple potato vine (*Solanum rantonnetii*), desert tobacco (*Nicotiana trigonophylla*), tree tobacco (*Nicotiana glauca*); **Verbenaceae:** St. Paul's verbena (*Verbena peruviana*).

**Investigator's Name(s):** William Roltsch[1], Greg Simmons[2] and Kim Hoelmer[3].

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**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** 1995 to 1997.

## Establishment of Introduced *Encarsia* species in Imperial Valley, CA

During the past two years several species/strains of *Encarsia* have been released into home gardens, field refuges and commercial fields. These include USDA accession numbers: uniparental M94056 (Brazil, >1 million); bi-parental, autoparasitoid *E. transvena* [M93003 (Spain, >150,000), M95107 (Multan, Pakistan, >200,000), M94041 (Thailand, >5,000), M94047 (Malaysia, >5000)] and *Encarsia sp.* M92018 (India, >300,000).

Released in the summer of 1996, *Encarsia transvena* M93003 did not persist at detectable densities in the field refuges through the winter, however, it did survive well on broccoli and collard at two home garden sites. At one of the sites it was monitored closely and found to increase its numbers considerably on broccoli during February, March and April of 1997. During mid-June of 1997, approximately 200,000 *Encarsia transvena* M95107 were moved from completed field cage tests to nearby field refuges consisting of okra, basil, roselle and cotton. This population increased dramatically on okra and nearby cotton, and also parasitized whitefly extensively on basil. During the fall of 1997, *Encarsia transvena* were common on yard plants in the southwestern portion and outskirts of Brawley. This represented approximately a 1 square mile area. They were common on roses, hibiscus, Cape honeysuckle, basil, broccoli, mulberry trees, and several less common species of plants. Samples have been submitted for DNA analysis. The present population most likely originated from M93003 and/or M95107. The two populations can be differentiated because M93003 has a unique banding pattern from all other *E. transvena* populations tested to date.

Numerous small releases of M94041 and M94047 occurred from the summer of 1995 until May of 1996, however there were no signs of lengthy establishment. M94056 was recollected in small numbers months after its release, however there are no signs of it having overwintered. *Encarsia* sp. M92018 has been detected in several field-collected samples following its release and in several urban samples. Its status is not well known at this time.

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**Research & Implementation Area**: Section D: : Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report**: 1997

## Systematics of *Eretmocerus*

Three new species were described and *Eretmocerus mundus* Mercet redescribed from series of specimens representing populations of *Eretmocerus* introduced and released against *Bemisia* (*tabaci* complex) in the U.S. Populations of *Eretmocerus* introduced from Hong Kong, Ethiopia and South Africa are being characterized and a comprehensive key to nominal North American and introduced species is in preparation. Specimens reared from *Bemisia* spp. from Australia are under examination.

**Investigator's Name(s):** Alvin M. Simmons and Matthew A. Ciomperlik[1].

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**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** July - November 1997.

## Establishment of Exotic *Eretmocerus* (Pakistan strain) in South Carolina

A study was conducted to evaluate the establishment of a Pakistan strain of *Eretmocerus* (M95012) on *Bemisia argentifolii* in South Carolina. The parasitoid was from a colony maintained at the Mission Biological Control Center, Mission, TX. Adult parasitoids were released on two plots at the U.S. Vegetable Laboratory farm in Charleston, South Carolina. One was a one acre field and the other was a half acre screened field plot planted in collard. The mesh of the screen was large enough for easy movement of whiteflies and parasitoids into or out of the plot. Before the collard plants were transplanted, they were infested with adult *B. argentifolii* from a greenhouse colony.

A single release of parasitoids was made in each plot. The parasitoids were released on heavily whitefly-infested plants within ca. a 3 m by 3 m area in the center of each plot. In the screened plot, 15,000 adult *Eretmocerus* were released on 15 July. In the open field plot, 30,000 adults were released 22 July. Starting in September, leaf samples were collected to determine percentage parasitism, and species diversity. Samples are still being processed.

Within season reproduction of the exotic *Eretmocerus* was observed in each of the release plots. Exotic *Eretmocerus* adults dispersed throughout both plots. Samples held for emergence of adult parasitoids showed the presence of an exotic *Eretmocerus*, an indigenous *Eretmocerus*, and indigenous *Encarsia* spp. *Eretmocerus* comprised a greater percentage (> 95%) of the parasitoids in the open field than in the screened plot (from ca. 55 to 75%). To determine the proportion of exotic to indigenous *Eretmocerus*, samples are being subjected to RAPD-PCR genetic analysis. Data will continue to be collected to examine the ability of the Pakistan *Eretmocerus* strain to survive the winter months in Charleston, SC.

**Investigator's Name(s):** Alvin M. Simmons and Kim A. Hoelmer[1].

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**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** 1997.

## Capture of *Bemisia* Parasitoids on Yellow Sticky Traps and Rate of Parasitism

Recent research has shown that the use of yellow sticky traps is a convenient method to survey for the parasitoids of *Bemisia argentifolii*. However, no work had previously been conducted to examine the correlation of the sticky trap captures with actual percentage parasitism *in the associated crop*. A field study was conducted to determine how the capture of parasitism on sticky cards relates to actual percentage parasitism in cole crops. Plots were set up in fields on the U.S. Vegetable Laboratory farm in Charleston, South Carolina and on a commercial farm in Imperial County, California. The crop (broccoli) in California was organically grown, and the crop (collard) in South Carolina only received a treatment of *Bacillus thuringiensis* before the sampling began. Yellow sticky cards were placed within the fields on wire holders. The cards were 15 cm from the ground and placed horizontally to the ground surface. The traps were replaced weekly. Also, weekly samples of leaves were collected from the plots and held in the laboratory for whitefly and parasitoid emergence. Data were collected on the numbers of each species of *B. argentifolii* parasitoids captured on the sticky cards and from the leaf samples. In addition, the numbers of adult *B. argentifolii* captured on the sticky traps and emerged from the leaf samples were recorded. Samples are still being processed and data are still being collected.

**Investigator's Name(s):** Gregory S. Simmons[1], Kim Hoelmer[2], Robert Staten[2] and Theodore Boratynski[1].

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**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** January 1997 to December 1997.

## Biological Control of Silverleaf Whitefly Infesting Cantaloupe with Large Scale Releases of Exotic Parasitoids in the Imperial Valley of California

During the spring of 1997, a large-scale demonstration project was conducted on four farms totaling 50 acres of spring melons. This project was initiated based on positive results from previous studies in small plots. These studies indicated that there was good potential for providing effective control of silverleaf whitefly by direct release of whitefly parasitoids. Parasitoid release in both Admire™ (imidacloprid) treated and organically grown melons had resulted in increased levels of parasitism and reduced levels of whitefly. The next step was to determine if parasitoid release on entire fields could be integrated with regular farm operations to provide season long control of whitefly.

An *Eretmocerus* species from the United Arab Emirates (species M95104) was selected for use in this demonstration as it has proven to be very effective against whitefly in the desert southwest. It has been observed reproducing in the field and can achieve high levels of parasitism on silverleaf whitefly infesting cantaloupe, cotton and cole crops. Releases of parasitoids were made over a four week period beginning after whitefly nymphs were first observed on melon leaves within the field. Parasitoids were released as pupae at rates ranging from 40,000 to 100,000 per acre depending on the level of whitefly infestation.

High levels of parasitism were achieved and whitefly levels were reduced in each of the release fields. In one field of mid-season planted organic cantaloupe, peak levels of parasitism ranged from 60 to 90% which resulted in a reduction of whitefly levels by as much as 94% relative to no-release fields. In another organically grown cantaloupe field, high levels of parasitism were also achieved ranging from 60 to 70% which resulted in a reduction of whitefly levels by 65% compared to nearby no-release check fields.

In two Admire™ treated fields, high levels of parasitism and reductions in whitefly levels were also achieved. Peak levels of parasitism ranged from 30 to 80% resulted in reductions in whitefly of 20 to 65% in comparison to no-release check fields. Though overall levels of whitefly were much lower in Admire™ treated than in organic cantaloupes there were still large reductions in whitefly as a result of parasite release. The high levels of parasitism and large reductions of whitefly achieved in the Admire™ treated fields, eliminated the need for late season applications of pyrethroids for whitefly control that are often needed after the effectiveness of the Admire™ application is reduced with time. This result adds to the results from previous studies which have demonstrated that parasite release is compatible with Admire™ treatment and can lead to very stable and effective control of whitefly infesting spring melons. Because of growing concern about the possibility of silverleaf whitefly evolving resistance to Admire™, combining the use of a non-chemical control measure (such as parasite release) with Admire™ treatment can help delay the development of resistance.

**Research Summary**
**Section D: Natural Enemy Ecology and Biological Control.**

Compiled by Charles H. Pickett

Over the last year major advances have been made in several key areas of biological control. These advances represent the culmination of the previous five years of research with continued focus on long term solutions to controlling *Bemisia*, and preventing their populations from exceeding economically damaging levels. Probably the most significant advancement in biological control has been the establishment of new exotic parastoids of *Bemisia*. Significant advances in augmentation biological control and our understanding of natural enemy biology and ecology have also been made.

Foreign exploration for natural enemies of *Bemisia* is largely completed and has included the Mediterranean region, south, central and southeast Asia, South America, the Arabian Peninsula and parts of Africa. Substantial evidence from Texas, Arizona, and California shows that several new exotic aphelinids have survived for one or more years following release. Exotic Aphelinidae are making up an increasing proportion of parasitoids emerging from field samples. They have also been collected several miles from original release sites. Differential survival of released species among regions of western United States suggests that climate is important to the permanent establishment and impact of these exotics. Field cage studies have assisted in determining which populations to emphasize during establishment efforts. A new key to the exotic *Eretmocerus* will soon be published and available this coming year. This key in combination with advances in molecular genetics provide essential tools needed for identifying recovered samples. Within two years, quick-blot hybridizations, with squashes of individual insects, may allow us to rapidly identify some exotic parasitoids to populations or strains. Studies on the interspecific interactions of native *Eretmocerus* and *Encarsia* are providing insight into the potential benefits or risks involved in releases of more than one genera of exotic aphelinid.

Large scale, augmentative releases of *Eretmocerus* show that biological control of *Bemisia* can be greatly increased in melons, possibly supplementing late season applications of pyrethoids. Costs for these releases are comparable to chemical costs for the same level of control. Augmentative releases made in both organically produced melons and on farms using conventional applications of imidacloprid, showed their use has potential for integration into conventional pest management practices. A completely novel approach to augmenting these parasitoids is being tested in Texas. "Banker Plants," i.e. transplants of melons inoculated with parasitoids prior to placement in fields, replace about 10% of the standard transplants going into a field. Application of imidacloprid removed many unparasitized whiteflies, with only minor impact to the parasitoids. This approach to inoculating fields with parasitoids can be integrated with conventional use of transplants with only minor adjustments to standard farming practices. Early season inoculation of spring melons with parasitoids can help to increase the regional build-up of these natural enemies, that in turn could disperse to mid- and late-year field crops, further reducing regional pesticide usage. Progress has been made in the use of insect diets. An encapsulation technique has been developed for Chrysopidae and *Geocoris* that could greatly reduce the mass rearing costs of these insects, a major problem to using augmentative biological control.

Conservation of natural enemies has seen major advances in the past year. The introduction of new insect growth regulators has helped to preserve many of the parasitoids and predators in cotton that may have been killed using conventional insecticides. A life table analysis this last year in cotton showed that predators can play an important role in controlling *Bemisia*. New formulations of *Beauveria bassiana,* soft on adult parasitoids, have also provided excellent control of whitefly nymphs attacking cotton. After five years of testing annual and perennial non-crop plants, some show promise for use in natural enemy refugia. Combinations of these plants can enhance the presence of important parasitoids, and are of great value when used as an outdoor insectary when initially releasing exotic parasitoids for regional establishment. They do not suffer the same problems as conventionally grown crops: e.g. pesticides, cultivation, rotation to other crops. Conservation of natural enemies using strips of land near and around field crops represents one of the least expensive ways of enhancing biological control, yet has received the least amount of attention from this body of researchers. Advances in a new marking technique may provide a tool for simplifying the study of regional insect movement. Using a protein with an ELISA system could provide a way to accurately, and quantitatively measure the impact of natural enemies in a crop that originated from a distant source.

**Table D. Natural Enemy Ecology and Biocontrol.**

| Research Approaches[a] | Year 1 Goals Statement | Progress Achieved Yes | Progress Achieved No | Significance |
|---|---|---|---|---|
| **Natural control and conservation:** | | | | |
| **Develop natural enemy conservation practices to reduce mortality to indigenous and introduced natural enemies.** | Conduct life table analyses of indigenous and introduced natural enemies to identify key mortality factors of natural enemy populations. | X | | New insect growth regulators tested well under field conditions, and reduced loss of natural enemies. A Life Table analysis was conducted on natural enemies in cotton. |
| **Evaluate potential of alternate plants to act as in-field refuges or insectaries for natural enemies.** | Identify potential plants for natural enemy population development and assess risks of these plants to foster additional pest problems. | X | | Combinations of annuals and some perennials show promise as within field natural enemy refugia. They are attractive to parasites but support low numbers of whiteflies. Annuals served as outdoor insectaries when releasing exotic parasitoids. |
| **Assess cues used by natural enemies to locate whitefly and to identify potential methods for enhancing natural enemy activity.** | Conduct laboratory tests to identify cues used by natural enemies to locate and attack whitefly. | | X | Some research has been initiated but was not reported at this meeting. |
| **Augmentation of natural enemies:** | | | | |
| **Develop natural enemy mass-rearing systems.** | Identify natural enemies with the highest potential for controlling whitefly in key cropping systems. | X | | Diets are being developed for generalist predators. Improvements have been made in rearing parasitoids, increasing rearing efficiency. Field studies have identified promising candidates for augmentative releases |
| **Develop release technologies to maximize the effectiveness of mass-reared natural enemies in the field.** | Identify natural enemies with the highest potential for controlling whitefly in key cropping systems and that may be economically mass produced. | X | | A novel "Banker Plant" field release strategy shows promise for increasing efficacy of releases. Releases of *Eretmocerus* into greenhouses controlled *Bemisia* attacking poinsettias when done at low pest densites. |

**Table D. Natural Enemy Ecology and Biocontrol. (continued)**

| Research Approaches[a] | Year 1 Goals Statement | Progress Achieved Yes | No | Significance |
|---|---|---|---|---|
| **Evaluate augmentative parasitoid, predator, or pathogen releases.** | Initiate studies on natural enemy augmentation with identified high potential natural enemies. | X | | Augmentative releases of parasitoids controlled *Bemisia* in large demonstration fields. These releases can be integrated with conventional pest management practices |
| **Importation biological control:** | | | | |
| **Evaluate the ability of exotic natural enemies to suppress whitefly populations under field conditions.** | Identify sites suitable for the release and subsequent evaluation of each candidate natural enemy. Conduct inoculative releases of natural enemies. | X | | Combinations of annual plants that make excellent insectaries and can be farmed under local climatic conditions have been identified. Homeowners are being recruited to care for plants used for making releases |
| **Systematics, ecology, and population dynamics of natural enemies:[b]** | | | | |
| **Clarify sytematics of predators, parasitoids and pathogens.** | Conduct taxonomic studies of species within targeted releases sites. Verify taxonomic purity of mass-reared natural enemies. Complete taxonomic work on poorly characterized but important groups. Assist in determining most suitable natural enemies for release through biogeographical analysis. | X | | Taxonomic studies have been completed on the exotic *Eretmocerus* and a key to their identification is in press. PCR techniques have been developed to identify the purity of cultures and aid in identification of recovered parasites. |
| **Determine *Bemisia*- natural enemy-host plant (Tritrophic) interactions.** | Initiate studies to identify mechanisms involved in *Bemisia*- and natural enemy plant attraction. | X | | Controlled laboratory studies showed that *Bemisia* and aphelind oviposition rates varied depending on host plant. |
| **Identify the attributes of natural enemy biology and population level interactions to explain biological control successes and failures.** | Assess the value of the *Bemisia* biological control research to evaluate key issues to the science of biological control. | X | | The role of autoparasitism in native populations of *Encarsia* and its impact on native *Eretmocerus* has been evaluated. Results from one study show no adverse affect of *Encarsia* on overall parasitism of SLWF |

[a] See Table C for complementary research.
[b] See Table A for complementary research.

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**Research and Implementation Area**: Section E: Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.
**Dates Covered by the Report**: August 1996-August 1997.

## Tolerance in Zucchini, *Cucurbita pepo L.*, to Whitefly-Induced Squash Silverleaf Disorder

Two zucchini breeding lines, (ZUC76) and ZUC33-SLR/PMR (ZUC33), which did not show silverleaf symptoms in field tests, were evaluated under greenhouse conditions. To determine the resistance mechanisms to the disorder, antixenosis, antibiosis, and tolerance tests to *Bemisia argentifolii* were conducted using 'Elite', a commercial variety susceptible to the disorder, as a control.

*Antixenosis-Choice Experiment.* One plant each of 'Elite', ZUC33 and ZUC76, at the 3-true leaf stage, was equally spaced within a 60 X 60 X 60-cm screened cage in the greenhouse. One hundred pairs, male and female, of whiteflies were released in the cage and insects were allowed to settle and oviposit on the plants. After 3 d, the number of eggs laid on both surfaces of all leaves in each of the cultivars was counted and trichome density on the abaxial surface was determined. No significant differences were found in the number eggs laid on each of the cultivars, which indicates a lack of oviposition preference by the insects. Eggs were found mostly on the three oldest leaves in all three cultivars. Number of trichomes did not differ significantly among cultivars and was significantly correlated with leaf age, with younger leaves being more hairy than older ones. Based on these results, it can be concluded that antixenosis, non-preference, is not the mechanism conferring resistance to silverleaf in ZUC33 and ZUC76.

*Antibiosis-No-choice Experiment.* One plant each of 'Elite', ZUC33 and ZUC76, at the 2-true leaf stage, was equally spaced within a 60 X 60 X 60-cm screened cage in the greenhouse. Fifteen pairs of whiteflies were aspirated into a 7-dram plastic vial clip cage. The insects were clipped onto the abaxial surface of the oldest leaf of each of the plants. After 2 d, all adults were removed and number of eggs on each plant was recorded. Eggs were allowed to hatch and immatures to develop. Whiteflies were aspirated daily until all insects emerged. Empty pupal cases were counted at the end of the experiment. Whitefly sex ratio, developmental time and survival, both from egg to adult, were determined and compared among 'Elite', ZUC33 and ZUC76. Resistance to silverleaf in the breeding lines does not seem to be due to antibiosis because even though time to 50% emergence was longer in ZUC33, the percent survival and percent female emergence was significantly higher in this breeding line. Additionally, time to 50% emergence in ZUC76 was significantly shorter than in 'Elite' however, sex ratio, and percent survival were not significantly different between these two cultivars.

*Tolerance Experiment.* Plants of all three cultivars, at the 2-true leaf stage, were covered with 1-gallon plastic vegetable bags and infested with either 0, 40, 80 or 160 pairs of whiteflies. Plastic bags and all whiteflies were removed after 3 d. Eggs were allowed to hatch and immatures to develop. When insects reached the red-eyed nymph stage, all leaves were removed from plants. Nymphs were counted and leaves were rated for silverleaf symptoms, from 0 (no silvering) to 5 (completely silvered). Number of nymphs was similar in all three cultivars and a significant linear relationship was found between whitefly infestation and number of nymphs. ZUC76 did not show silverleaf symptoms at any of the infestation levels tested. 'Elite' showed maximal silverleaf symptoms even at the lowest infestation level of 40 pairs of whiteflies. ZUC33 showed silvering only at infestation levels of 80 pairs of whiteflies or above. 'Elite' was significantly more affected by the silverleaf disorder than was ZUC33. Overall mean number of silvered leaves was 3.7 and 0.7 and average silverleaf rating was 3.04 and 0.63 for 'Elite' and ZUC33, respectively. The results from this experiment indicate that tolerance to whitefly feeding is the mechanism responsible for the resistance to silverleaf in ZUC33 and ZUC76.

**Investigator's Name(s)**: C.C. Chu, E.T. Natwick, T.J. Henneberry, and A.C. Cohen.

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**Research & Implementation Area**: Section E: Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

**Dates Covered by the Report**: 1997.

## No-Choice Study of Cotton Cultivar Susceptibility to Silverleaf Whiteflies in the Greenhouse

Results with nine cotton cultivars (Deltapine 50, 5409, 5415, 5432, 5461, 5517 and 5690, Louisiana 887 and Stoneville 474) conducted in 1997 in a greenhouse showed no differences among cultivars for silverleaf whitefly infestations. The results suggest whitefly preference occurs at mixed cultivar plantings but under no choice conditions, all cultivars tested were susceptible to whitefly infestation.

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**Research & Implementation Area**: Section E: Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

**Dates Covered by the Report**: 1992 - 1996.

## Choice Study of Cotton Cultivars Susceptible to Silverleaf Whiteflies in Fields

Results of studies with 17 cotton cultivars conducted from 1992 to 1996 in the Imperial Valley, California showed difference in cultivars susceptibility to silverleaf whitefly colonization. In 1992, Deltapine (DPL) 20 and 90 had fewer whiteflies and higher lint yields compared to DPL 50 and Chembred 1135. In 1993, DPL 5415 had the least number of whiteflies compared with three other Deltapine and four other Chembred cultivars studied. In 1993, Louisiana (LA) 887 had the highest number of whiteflies compared to four other Deltapine cultivars and had the lowest yield. In 1995 and 1996, when insecticides were applied at an action threshold of 4.1 adults per leaf-turn, lint yields of cultivars tested were similar, but numbers of insecticide mixture applications required were different. In 1995, 4 to 5 insecticide applications were applied to DPL 5415 and DPL 5461 while 6 to 7 applications were applied to Stoneville 474 and Louisiana 887. In 1996, based on the same threshold, the two Deltapine cultivars were treated 7 times and Stoneville 474 and Louisiana 887, 8 times.

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**Research & Implementation Area**: Section E: Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

**Dates Covered by the Report**: 1996.

## Relationship Between Leaf Morphology and Silverleaf Whitefly Densities on Deltapine Cotton Cultivars

Eight Deltapine (DPL) cultivars were planted in Holtville, CA in 1996 to investigate the relationship between leaf morphology and silverleaf whitefly densities. The cultivars tested were DPL 20, 50, 90, 5415, 5432, 5461, 9050, and DPX 9057. Results showed that whitefly adult and nymph densities were significantly related to the distance from abaxial leaf surface to the center of minor vascular bundles. Correlation coefficients were –0.79 and –0.71 for adults and nymphs, respectively. Leaf thickness and thickness of the abaxial epidermal layer were not correlated to whitefly adults, nymphs or eggs.

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**Research & Implementation Area:** Section E: Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

**Dates Covered by the Report:** 1997.

## Host-evaluation Behaviors of *Bemisia* and their Modification by Systemically-applied Imidacloprid

Behavioral observations were made of adult *Bemisia tabaci* (biotype B) during the first 20 minutes on host plant leaves to quantify and catalog the details of the host-plant acceptance behaviors. The influence of insecticide application on behavior was studied by observing insects on either untreated cotton leaves, or those to which the chloronicotinyl insecticide, imidacloprid, had been applied as a foliar or systemic treatment. Observations on these leaves were conducted for four strains of *B. tabaci* which varied in their level of resistance to this compound, to determine whether between-genotype variation exists in the response of *B. tabaci* to host plants, and to imidacloprid. Host evaluation behaviors were dominated by probing of the leaf surface. The duration of probing was similar on untreated and foliar treated leaves, but markedly different on those treated systemically. After their first probe, whiteflies on these leaves were much more active, spending significantly greater time walking and dabbing the labium onto the leaf surface. There was also a concurrent 50% reduction in the total time spent probing into systemically-treated leaves, compared to the other treatments, due to shorter mean probe durations. The frequency of probing was not affected by treatment method, however. Egg laying behaviors was significantly more common, and lasted longer on the systemically treated leaves.

Results from this study show that the host evaluation phase of *B. tabaci*-host interactions is dominated by probing, and that the time spent in a particular behavior is significantly affected by imidacloprid when the whitefly comes in contact with it in its diet, rather than on the leaf surface. Our findings have wider implications for understanding whitefly-host plant interactions and the mechanism of host plant acceptance.

**Investigator's Name(s):** C.S. LeVesque, Thomas M. Perring, B.K. Moore, A. Cooper & L.L. Walling.

**Affiliation & Location:** Department of Entomology, and Department of Botany and Plant Sciences, University of California, Riverside, CA. 92521.

**Research & Implementation Area:** Section E: Host Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

**Dates Covered by the Report:** January 1, 1997- December 31, 1997.

## Impact of silverleaf whitefly feeding on tomato fruit physiology

Feeding by the silverleaf whitefly, *Bemisia argentifolii*, results in the induction of several developmental disorders in specific host plants. These include leaf silvering in squash, and irregular ripening in tomato. It has been determined that these developmental disorders can be induced only during specific periods in the development of the affected plant organ. Because squash leaf silvering symptoms develop rapidly in response to the feeding of small numbers of immature silverleaf whiteflies, correlating insect feeding with the period of leaf differentiation and expansion vulnerable to disorder induction has been straight forward. However, due to the length of time between tomato flower formation and fruit ripening, making a similar determination for the tomato irregular ripening disorder has been more involved. In these experiments tomato plants were pruned to two main stems after the formation of 10 true leaves. Insect infestations were established on the four leaves closest to the branch point by introducing 200 females and 50 males into organdy sleeve cages enclosing each leaf. Flowers formed above the branch point were tagged at the fully opened stage and their position determined in relation to the insect infestations. The developed fruit was collected thirty-five days later at the mature green stage and held at room temperature in an illuminated BOD box (16hr l:8hr d) for two weeks to ripen. Measurements of weight, compressibility and ethylene evolution were made three times during the ripening process. After ripening, fruit were scored for the development of irregular ripening symptoms and the pericarp and seeds harvested separately for RNA extractions. A subset of fruit were used for ultrastructural studies to determine changes in plastid transformation from chloroplast to chromoplast. The densities of insects in each infestation was determined by direct counts from leaves taken from plants used solely for this purpose. A total of four additional infestations were established on each plant over the course of the experiment. At the termination of the experiment, sets of fruit had been collected that had been exposed to a variety of insect densities at different stages of flower and fruit formation. No changes in the development of fruit plastids was noted. In the arrested green tissue of fruit, chloroplasts were found, and in the red tissue sectors, chromoplasts were found. No intermediate or unusual plastid forms were detected. Correlation of reduction in ethylene evolution, fruit softening and the accumulation of ripening-related gene transcripts with feeding by silverleaf whiteflies showed that flower formation is the critical period of tomato fruit development affected in the irregular ripening disorder. This information is essential to elucidate the mechanism of induction of the irregular ripening disorder.

**Investigator's Name(s):** Eric T. Natwick[1], C.C. Chu[2], T.J. Henneberry[2], D. Brushwood[3] & Charles Cook[4].

**Affiliation & Location:** [1]University of California Cooperative Extension, University of California Desert Research and Extension Center, 1050 E. Holton Road, Holtville, CA 92250; [2]USDA-ARS, Western Cotton Research Laboratory, Phoenix, AZ; [3]USDA-ARS Cotton Quality Research Station, Clemson, SC; and [4]USDA-ARS, Weslaco, TX.

**Research & Implementation Area:** Section E: Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

**Dates Covered by the Report:** March 1997 through December 1997.

## Silverleaf Whitefly Infestation Levels in Relation To Cotton Variety

Sixteen cotton varieties were sown at the UC Desert Research & Extension Center into plots of a randomized complete block design experiment replicated four times, and irrigated 28 March, 1997. Varieties in the trial included: DP 20, DP 50, DP 90, DP 5415, DP 5432, DP 5461, DP 9050, DP 9057, CB 1135, Texas 121, and C 118-2-93 from the US; and CS 50, Siokra L23, Siokra V-15, Siokra 1-4, Siokra S-101, and 89230-341-907 from Australia. Individual plots measured 14 m in length with 4-beds on 1 m centers. No insecticides were applied to the cotton plots. Silverleaf whitefly adults were sampled from ten plants at random in each plot via the leaf turn method using the 5th main stem leaf from the terminal on 19 & 25 June, and 2, 9, 16, & 23 July, and 1, 6, & 13 August, 1997. Silverleaf whitefly eggs and nymphs were counted on 1.54 $cm^2$ leaf disks of from ten 5th position leaves down from the terminal extracted from randomly selected plants in each plot on 6, 19 & 25 June, and 2, 9, 16 & 23 July, and 1, 6, 13 & 19 August, 1997. Yield data were recorded on September 3, 1997. Seed cotton was hand picked from 0.002 acre per plot. Cotton samples were ginned at the USDA-ARS, Western Cotton Research Laboratory in Phoenix, AZ and lint samples have been sent to the USDA/ARS Cotton Quality Research Station in Clemson, SC for stickiness and sugar analysis.

All but Siokra S-101 and Siokra V-15 among the Australian varieties had the lowest seasonal means for whitefly adults among all of the entries in the trial. Among the Australian varieties, all but Siokra V-15 had the lowest seasonal means for whitefly eggs among all of the entries in the trial. The Australian seed-line 89230-341-907 had a seasonal mean value for whitefly nymphs that was lower than all other varieties, Pœ 0.01. Siokra L23, DP20, and Siokra 1-4 had low seasonal mean values for nymphs, but were not significantly lower than most other cotton varieties. The trichome density for the Australian seed-line 89230-341-907 (0.18/$cm^2$) was also lower than all cotton varieties with the exception of Texas 121 with a trichome density of 0.34/$cm^2$. There were no other differences among the cotton varieties for seed cotton yield.

**Investigator's Name(s):** Eric T. Natwick[1], C.C. Chu[2], T.J. Henneberry[2], Charles Cook[3], R.L. Gilbertson[4] & D. Brushwood[5].

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**Research & Implementation Area:** Section E: Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

**Dates Covered by the Report:** March 1997 through December 1997.

## Silverleaf Whitefly Infestation and Cotton Leaf Crumple Virus Symptoms in Relation to Cotton Genotype

One cotton cultivar and five cotton seed-lines were sown at the UC Desert Research & Extension Center into plots of a randomized complete block design experiment replicated six times, and irrigated 28 March, 1997. The cotton cultivar was Texas 121 and the seed-lines were C118-2-93, C95-2103, C95-383, C95-3109, and C95-483. Individual plots measured 12.5 m in length on single seed-beds on 1 m centers. No insecticides were applied to the cotton plots. Silverleaf whitefly adults were sampled from ten plants at random in each plot via the leaf turn method using the 5th main stem leaf from the terminal on 16, 23 & 30 June, and 7, 14, 21, & 28 July, and 3 & 11 August, 1997. Silverleaf whitefly eggs and nymphs were counted on 1.54 $cm^2$ leaf disks of from ten 5th position leaves down from the terminal extracted from randomly selected plants in each plot sampled on the same dates as the adults. Cotton leaf crumple virus (CLCV) rating evaluations were preformed on 7 & 18 August. The CLCV ratings were as follows: 1 = no CLCV symptoms, 2 = mild symptoms, 3 = moderate symptoms, and 4 = severe CLCV symptoms. Yield data were recorded on September 3, 1997. Seed cotton was hand picked from 0.001 acre per plot. Cotton samples were ginned at the USDA-ARS, Western Cotton Research Laboratory in Phoenix, AZ and lint samples have been sent to the USDA/ARS Cotton Quality Research Station in Clemson, SC for stickiness and sugar analysis.

All of the seed-lines and the cultivar Texas 121 had similar numbers of silverleaf whitefly adults with mean separations on a couple of sampling dates, but no significant differences for the seasonal means. The seed-line C95-483 had fewer whitefly eggs than C95-3109 for seasonal mean values, SNK, Pœ 0.01, with no other significant differences among the seed-lines. The seasonal mean for nymphs for C95-483 was lower than that of C118-2-93 and that of C95-3109. C95-2103 also had fewer nymphs for a seasonal mean value than C118-2-93. On 7 August C95-2103 and C95-383 had no CLCV symptoms, C95-3109 had a rating of 1.08, C95-483 had a rating of 1.42, Texas 121 had a rating of 1.58, and C118-2-93 had a rating of 1.92. CLCV ratings on 18 August were as follows: C95-383 (1.25), C95-2103 (1.33), C95-3109 (1.83), Texas 121 (2.17), C95-483 (2.25), and C118-2-93 (2.83). The presence of CLCV in cotton samples was confirmed at the Plant Pathology Department at UC Davis. The cultivar, Texas 121, had a greater seed cotton yield than any of the seed-lines, but there were no differences among the seed-lines for seed cotton yield.

**Investigator's Name(s):** David Puthoff, Thomas Perring and Linda Walling.

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**Research & Implementation Area:** Section E: Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

**Dates Covered by the Report:** 1996.

## The Tomato Defense Response to Silverleaf Whitefly Feeding

We have demonstrated that Pathogenesis Related mRNAs accumulate in response to silverleaf whitefly-infested and greenhouse whitefly-infested and apical non-infested leaves of tomato plants. Transcript levels for several wound-response genes were also monitored and only the PAL was induced by whitefly feeding. We have also identified, using mRNA differential display, a gene that is specifically induced by both silverleaf and greenhouse whitefly feeding. This gene is not induced following mechanical wounding or bacterial infection. However, it is induced following ethylene treatment and jasmonic acid treatment. This whitefly induced gene is being sequenced at the present time. Further characterization will be conducted including the generation of anti-sense plants.

**Investigator's Name(s):** David P. Puthoff, Thomas M. Perring, & Linda L. Walling.

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**Research & Implementation Area:** Section E: Host Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

**Dates Covered by the Report:** January 1, 1997- December 31, 1997.

## The size of the silverleaf whitefly (*Bemisia argentifolii* Bellows & Perring) haploid genome

The silverleaf whitefly (*Bemisia argentifolii* Bellows and Perring) has become a major agricultural pest throughout the world. This pest has a wide host range, transmits a number of debilitating viruses, and processes large quantities of phloem which results in large honeydew deposits that promote fungal growth. The silverleaf whitefly also is responsible for several plant developmental disorders, one of which is squash silverleaf from which it has acquired its common name. Although basic research on this pest has been ongoing for several years, the molecular research on this phloem-feeding insect is in its infancy. Genome size determination of this newly distinguished species will facilitate further molecular studies. The size of the *Bemisia argentifolii* genome was determined by measurement with 4', 6-Diamidine-2'-phenylindole dihydrochloride (DAPI) fluorescence of haploid nuclei.

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**Research And Implementation Area**: Section E: Host Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

**Dates Covered By Report**: August 1996 to December 1997

## Effect of the Glabrous Leaf Trait on Whiteflies and Melon Yield

Glabrous melons were found to consistently reduce whitefly numbers in field trials in south Texas. Further tests were conducted to introduce the glabrous leaf trait into a commercial type cantaloupe cultivar and evaluate the line in the field for response to whitefly and melon yield. TAM Sun (selfed selection out of Sunshine, an F1 hybrid from Ferry Morse) was crossed with a glabrous phenotype in the variety SR-91 (single gene recessive trait, J. Herid. 54:113-115). Split plot field experiments were conducted in fall 1996 and spring 1997. Main Plots: 1) Admire-treated and 2) non-treated, Subplots: 1) Explorer, 2) Cruiser, 3) F2 glabrous, 4) F2 pubescent. Whitefly counts were made through the season and yield data was collected to measure plant response. The results indicated that the glabrous-leaf melons consistently resulted in reduced whitefly adult and nymphs. Also, the currently available glabrous line (F2) was not significantly different in yields compared with commercial standards. Glabrous-leaf melons had significantly lower vine length and % sugars in the spring of 1997, but not in the fall of 1996, possibly due to seasonal differences. Currently in 1998, a small amount of F3 seed is available for testing.

**Investigator's Name(s):** Alvin M. Simmons.

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**Research & Implementation Area:** Section E: Host Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

**Dates Covered by the Report:** 1997.

## Subsistence of *Bemisia* on Upper and Lower Leaf Surfaces of Selected Vegetables

*Bemisia argentifolii* is generally found on the lower surface of most host plants, but from about 1% to over 60% of the immature population may be found on the upper surface. Most studies have been conducted on *Bemisia* on the abaxial leaf surface. However, it would be useful to know the fate of those that occur on the adaxial leaf surface. A study was conducted to determine any influence of leaf surface on immature survival and adult body size of *B. argentifolii,* and determine the likelihood of movement by the crawler from the adaxial leaf surface on selected vegetable hosts. Laboratory tests were conducted on cantaloupe, collard, cowpea, bell pepper, and tomato.

On the upper surface, survival to the first stadium was high (85-95%) on all crops. Movement of the crawlers from the upper to the lower surface was high on pepper (ca. 80%), cantaloupe (ca. 55%), and cowpea (ca. 55%). Conversely, less movement to the lower surface was observed on collard (ca. 18%) and tomato (ca. 30%). Only a small negative response to light by the crawler was detected. Thus, the impetus to move is apparently primarily a response to feeding and tactile cues. Survival was similar between whitefly nymphs on the upper and lower leaf surfaces for each crop, except significantly more survived on the lower surface of cowpea compared with the upper surface. Data are still being collected on adult body size.

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**Research & Implementation Area:** Section E: Host-Plant Resistance, Physiological Disorders, and Host-plant Interaction.

**Dates Covered by the Report:** 1997.

## Assays Of Melons For Resistance To *Bemisia.*

Melons are highly attractive hosts for *Bemisia argentifolii*. We have been conducting studies on western U.S. shipping-type melons for plant resistance against *B. argentifolii* over the past few years. Selected germplasm entries from our previous trials were used for further evaluation. Data from 1997 laboratory and greenhouse tests were collected from bioassays for plant tolerance, antibiosis, and antixenosis. "Top Mark" was used as the commercial standard in the tests. Plant survivability, plant condition, and size and biomass of different plant parts were determined. Whitefly survival from egg to adult was variable and ranged from about 95% on "Top Mark" to 50-70% on some entries. Using selected resistant germplasm, inbred and $F_1$ families were made, and the seeds were field-planted for additional evaluations against natural whitefly infestations in the southwest. In the field, not all $F_1$ progenies had fewer whitefly eggs than "Top Mark." The inbred entries generally demonstrated higher whitefly resistance than the $F_1$ families, based on whitefly density. The data indicate that the mechanisms of resistance in melon are not necessarily synchronized within a given entry. For example, an entry with good plant tolerance to whitefly feeding may or may not also result in a deleterious effect on the performance of *B. argentifolii* compared with the susceptible commercial standard.

**Investigators Names**: J.R. Stavely, R.T. McMillan, Jr., J.S. Beaver, and P.N. Miklas.

**Affiliation & Location**: Agricultural Research Service, Beltsville, MD, Florida Tropical Research and Education center, University of Florida, Homestead, FL, Department of agronomy and Soils, University of Puerto Rico, Mayaguez, PR, and Agricultural Research Service, Prosser, WN.

**Research & Implementation Area**: Section E: Host Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

**Dates Covered by the Report**: 1997

## Three McCaslan Type, Indeterminate, Rust And Golden Mosaic resistant Snap Bean germplasm Lines, Beldade-RGMR -4, -5, and -6

The Agriculture Research Service, U.S. Department of Agriculture, the Florida Agricultural Experiment Station, and the Puerto Rico Agricultural Experiment Station, released three rust and bean golden mosaic geminivirus(BGMV) resistant (RGMR), white seeded, indeterminate (pole), flat podded, market type, snap bean germplasm lines BelDade-RGMR-4, -5, and -6. These lines are horticulturally very similar to rust and golden mosaic susceptible cultivar McCaslan 42 in pod and plant characteristics. They were developed specifically for resistance to all 87 available races of the bean rust fungus Uromyces appendiculatus, as well as to the strain of BGMV that occurs in Puerto Rico and that was first found in Dade County, southern Florida in early 1993. BelDade-RGMR-4, -5, and -6, like McCaslan 42, are homozygous for the I gene for resistance to strains of bean common mosaic virus that that have been found in Florida. BelDade-RGMR-4, -5, -6 are the first commercial snap or dry beans having BGMGV resistance that have been developed for the United States.

The source of BGMV was a Puerto Rican, indeterminate snap bean breeding line, 9356-1-3, derived from a cross of cultivar 'Triumph' with BGMV resistance line A429. Line 9356-1-3 contains a single recessive gene, bgm-1, from A429 for BGMV resistance. A polymerase chain reaction-random amplified polymorphic DNA marker, tightly linked to bgm-1, has been identified and was used to identity plants containing the recessive gene in homozygous recessive (resistant), heterozygous or homozygous dominant (susceptible) condition.

**Investigator's Name(s):** W.T.G. van de Ven, T.M. Perring, and L.L. Walling.

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**Research & Implementation Area:** Section E: Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

**Dates Covered by the Report:** January 1, 1997 - December 31, 1997.

## Genes Involved in Silverleaf Whitefly Induced Squash Leaf Silvering

Using RNA differential display changes in squash gene expression in response to the silverleaf whitefly (SLWF) and sweetpotato whitefly (SPWF) were identified. Apical, non-infested leaves of 3 developmental stages were examined from SLWF, SPWF and control plants. Four classes of genes were identified: 1) Constitutive expressed genes, 2) developmentally regulated genes, 3) whitefly defense response (WDR) genes and 4) silverleaf whitefly response (SLW) genes. Four SLW genes have been further characterized by hybridization, sequence analysis and complementation studies. SLW1, 2 and 3 are induced by SLWF feeding in all 3 leaf stages, while SLW4 is suppressed by SLWF feeding in young leaves. The SLW genes were not modulated by SPWF infestation

## Research Summary

### Section E. Host-Plant Resistance, Physiological Disorders, and Host -Plant Interactions.

Compiled by Eric Natwick

Advancements are continually being made to fill key knowledge gaps and to provide usables for plant growers. Various research avenues are being approached to address host plant resistance to whitefly, diseases, and plant disorders on row and vegetable crops. Mechanisms of resistance and modes of action for whitefly and disease resistance are being studied. Efforts are being made to select for plant traits associated with whitefly resistance and to incorporate these and other unidentified resistance traits into commercially acceptable germplasm. Numerous cotton cultivars and seed lines were evaluated against whitefly infestation, plant quality, and susceptibility to cotton leaf crumple virus. All cotton cultivars evaluated in a no-choice field test were susceptible to whitefly infestation. In melon, selections have been made using several genetic entries, including a glabrous leaf type that exhibits whitefly resistance. Crosses with commercial cultivars were made, and progenies and inbreeds were evaluated for whitefly density, survival, antixenosis, and plant tolerance. In collard and broccoli, plants with the glossy leaf character displayed whitefly resistance and are being examined further using advanced lines and their progenies. Antixenosis, antibiosis, and plant tolerance studies were conducted in squash. Plant geneticists, horticulturists, entomologists, and others are being more involved in a team research approach. This multiple discipline approach is critical to continued expeditious progress. While work on some resistant germplasms is in more advanced stages of progress than others, additional research continues on searching for new potentially resistance germplasm.

Molecular biological approaches are being developed for resistance to whitefly, diseases, and plant disorders. Work is being conducted to characterize the nature of new plant physiological syndromes that have appeared with the new biotype/species and with the increase in whitefly populations. Whitefly related diseases and plant disorders are being addressed in tomato, squash, and cotton. Efforts are being undertaken to better understand the mechanisms of these abnormalities and to obtain genetic materials that have resistance. In tomato, a gene has been identified that is specifically induced by whitefly feeding. Data have showed that antixenosis is not the mechanism responsible for resistance to the squash silverleaf disorder in two zucchini lines. Four classes of genes were identified in inducing squash leaf silvering. Whitefly feeding behavior data have shown that the host evaluation phase of *Bemisia*-host interactions is dominated by probing. This will help better understand the whitefly-host plant interactions and the mechanisms of host acceptance. Movement of the crawler stage from the upper leaf surface was influenced by host and was primarily in response to feeding and tactile cues. Intercropping of susceptible with resistant cole crops did not result in a reduction of whitefly infestation. Refinement is being made on the whitefly artificial feeding and rearing systems. Attempts are being made to better define whitefly-plant interactions and to identify plant characteristics that may be useful in developing plant resistance approaches for control.

**Table E. Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.**

| Research approaches | Year 1 Goals Statement | Progress Achieved Yes | No | Significance |
|---|---|---|---|---|
| **Characterize resistance mechanisms and identify chemical/morphological components, and study effects of insect adaptation.** | Identify potential sources of germplasm for disease, plant disorders and whitefly resistance.[a] | X | | Research was conducted on identifying potential sources of germplasm for whitefly resistance in alfalfa, cotton, melon, cole crops, and cucurbits; and resistance to virus symptoms and silverleaf disorder in cotton and cucurbits, respectively. These studies included research on plant tolerance, antibiosis, and antixenosis. Antixenosis was found not to be responsible for resistance to squash silverleaf in two zucchini lines. |
| **Develop molecular level techniques to produce resistant germplasm.** | Identify physiological processes of whiteflies to target for inhibition. | X | | Characterization of plant genomone was demonstrated in tomato and squash. Pathogenesis related mRNAs accumulated in response to whitefly feeding on tomato leaves. Data on whitefly probing behavior indicates that host evaluation phase of *Bemisia*-host interaction is dominated by probing. |
| **Incorporate resistance traits into commercial genotypes.** | Identify and isolate genetic sources of resistance for transformation and/or breeding. | X | | From promising genetic materials, inbreeds, $F_1$ and $F_2$ progenies, and assorted cultivars were studies for whitefly resistance (in alfalfa, cotton, melon and squash), and susceptibility to diseases (in cotton) and plant disorders (in squash). Including plant geneticists and other specialists on the research team has been an asset. |
| **Determine influence of host plant morphology, physiology and phenology on feeding behavior and competition.[b]** | Characterize nutritional and other preference properties of various host plants. | X | | Research was studied on the acceptability of cotton and vegetable hosts on whitefly feeding behavior. Work was conducted on distance from abaxial surface to minor veins, and feeding response on abaxial and adaxial surfaces of different hosts. |
| **Define whitefly feeding and oviposition behavior and investigate approaches for interrupting whitefly feeding and digestion.[c]** | Investigate approaches for interruption of feeding, assimilation, development and reproduction. | X | | The host evaluation phase of *Bemisia*-host interactions was shown to dominate by probing, and the time spent in a particular behavior was affected by imidacloprid when the whitefly came into contact with the chemical in its diet rather than on the leaf surface. Intercropping of resistant within susceptible cole crops did not lessen the abundance of whiteflies. |

**Table E. Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions. (Continued)**

| Research approaches | Year 1 Goals Statement | Progress Achieved Yes | Progress Achieved No | Significance |
|---|---|---|---|---|
| **Study whitefly toxicogenic plant reactions.** | Determine effects of whitefly feeding on host plant physiology, morphology and anatomy. | X | | Research on tomato identified a gene that is specifically induced by whitefly feeding. Four classes of genes were identified in inducing squash leaf silvering. These genes were further characterized by hybridization, sequence analysis and complementation studies. |

[a] See Table B for additional plant disease resistance research.
[b] See Section A.
[c] See Section A, approach #9.

**Section F: Integrated and Areawide Pest Management Approaches, and Crop Management Systems**
Co-Chairs: Peter Ellsworth and John Norman

**Investigator's Name(s)**: James R. Brazzle, Brian Fien, & Nick Toscano[1]
**Affiliation & Location**: Univ. of CA, Coop. Ext., Kern County, CA; [1]Dept. of Entomology, Univ. of CA, Riverside, CA
**Research & Implementation Area**: Section F: Integrated and Areawide Pest Management Approaches and Crop Management Systems
**Dates Covered By The Report**: 1997

## Silverleaf Whitefly in the Southern San Joaquin Valley: An Areawide Management Project in Progress

Silverleaf whitefly, *Bemisia argentifolii*, first appeared in cotton, melons and ornamental plants in the San Joaquin Valley (SJV) during 1992. The next few years were characterized by localized outbreaks in the southern and eastern portions of the SJV. In 1996-97, a significant increase in distribution, host range, earliness, and population levels were observed. The successful management of these changing whitefly populations in the San Joaquin Valley is dependent upon IPM, resistance management and hard work. As observed in 1997, chemical tools (particularly the use of the insect growth regulators (IGR's)) are an integral part of a whitefly management program. However, the efficacy of these products depends upon a good scouting program, use of the action thresholds and judicious application of each tool. A high quality program must also include cultural management techniques tailored on a regional basis. In the SJV a high premium should be placed on host plant sanitation, cotton management and intensive scouting to assist in good decision making.

The elevated pest status given to silverleaf whitefly has resulted in a large amount of information on possible management techniques. However, little effort has been made to integrate and implement this information at the field level. Other areawide programs have been initiated, however these efforts are focused on chemical control excluding other important management techniques. In 1997, with the cooperation of growers, ginners, production crop advisers, CDFA, University of California researchers, and support of the California Cotton Pest Control Board, an integrated areawide management program tailored for the San Joaquin Valley was initiated.

In Kern County, California two areas of land were designated to evaluate the impact of this areawide program on the build up of insecticide resistance, cotton lint quality and pest management efficacy and costs. One area of 7500 contiguous acres of land integrated best management techniques such as; cotton management for earliness and good defoliation, host plant sanitation (e.g. weeds, melon regrowth), limited beneficial disruption, intensive monitoring and close adherence to action thresholds. All techniques where employed on a regional basis. 3800 acres conventionally managed (an uncoordinated management approach). Both regions included a range of crops including carrots, grapes, potatoes, grain, cotton, corn and melons were included in the areawide managed region only.

Adult and immature whitefly populations were monitored in all crops throughout the season with an emphasis placed on cotton. Whitefly populations in the areawide and conventionally managed regions tracked one another through late August. At this time and continuing through September whitefly levels in the conventionally managed fields increased significantly compared with whitefly levels in the areawide region. By late September, whitefly levels in some conventionally managed fields were 4 times greater. A similar trend was observed in both adult and immature populations. Although some variability existed all conventionally managed cotton fields hosted greater levels of silverleaf whitefly than levels observed in the areawide managed fields.

In terms of lint quality, field observations suggested significant differences. However, quantitative measures were taken to better describe observed differences. Prior to defoliation bolls were collected from all fields, hand ginned and tested for stickiness with the aid of a SCT Thermodetector. Results revealed a pooled mean of 19 (N = 68) sticky points per 20 boll sample in the conventionally managed region and 7.5 (N = 128) sticky points per 20 boll sample in the areawide managed region.

Although, integrated areawide management in the SJV is in its infancy and full economic analyses are pending we are excited about the prospects.

**Investigator's Name(s)**: S. J. Castle

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**Research & Implementation Area**: Section F: Integrated and Areawide Pest Management Approaches, and Crop Management Systems

**Dates Covered By The Report**: 20th Century

## Primary Pest or Synthetically Induced? The Role of Insecticides and Other Factors in the Pest Status of *Bemisia tabaci*

Among research and review articles published in the past 20 years that considered in some degree the pest status of *Bemisia tabaci*, a preponderance indicated that insecticide use had played a significant role in its development into a major pest. Both direct and indirect effects of insecticides on field populations of *B. tabaci* were implicated in exacerbating management efforts. For example, Eveleens (1983, Crop Protection 2:273-287) reviewed the whitefly crisis in the Sudan Gezira in the late 1970s and concluded that decimation of natural enemy populations through non-targeted exposure to insecticides had indirectly led to whitefly outbreaks. But in their review of the same crisis, Dittrich et al. (1985, Crop Protection 4:161-176) argued that Eveleens' 'beneficial insect hypothesis' was incorrect because direct mechanisms involving whiteflies, such as resistance to organophosphorous insecticides and fertility stimulation by DDT residues, were the most important causes of the outbreaks. The underpinning of either argument, however, was that intensive spraying of insecticides resulted in a whitefly crisis in the Sudan Gezira. Subsequent articles by other authors (e.g. D. N. Byrne et al., 1990, pp. 227-261 in "Whiteflies: Their Bionomics, Pest Status and Management" ed. D. Gerling; F. J. Byrne & A. L. Devonshire, 1993, Pestic. Biochem. Phys. 45:34-42) also suggested that both direct and indirect effects of insecticide use had been the most important causes of crisis situations associated with whitefly outbreaks in general.

Critical evaluation of the hypothesis that whiteflies are essentially an upset pest induced by intensive insecticide use requires that case histories of whitefly outbreaks be examined to determine if chemical control was an integral part of all documented outbreaks. Any deviation from this pattern, i.e. outbreaks occurring in systems where insecticide use was nil, could be interpreted as counter-evidence to the stated hypothesis. In addition, examples of agroecosystems where insecticides are used intensively and *B. tabaci* is well-established, yet does not increase to crisis levels, would argue that other factors are at least equal in importance to the relative intensity of insecticide use in determining levels of whitefly infestations (assuming that susceptibility to insecticides are similar in outbreak and non-outbreak regions).

The dispersion of *B. tabaci* around the globe offers the opportunity to examine patterns of infestation in different regions that vary not only in their management practices, including insecticide inputs, but also in their climates and cropping systems. It should not be overlooked that across the vast range where *B. tabaci* is found, relatively benign, endemic populations are more common than epidemic populations. Accounts of historical *B. tabaci* outbreaks also provide an essential perspective on present day outbreaks by demonstrating serious pest potential under conditions of less intensive management. Outbreaks that occurred prior to the advent of synthetic organic insecticides suggest an insect that, under the right set of conditions, was worthy of primary pest status without invoking causation by conventional insecticide-related factors. The full set of observations on *B. tabaci* infestations, historical and modern, epidemic and endemic, need to be examined collectively to better understand variable densities of *B. tabaci* populations.

There is outstanding documentation of *B. tabaci* outbreaks in the Punjab region of India during the 1920s and 1930s. Husain and Trehan (1933, Indian J. Agric. Sci. 3:701-753) presented extensive quantitative data that showed immature whitefly densities on cotton in excess of 20 nymphs per $cm^2$ on four consecutive sampling dates in August and September, 1929. In the Sudan Gezira, average adult emergence per leaf from a sample of 200 *Dolichos lablab* leaves reach almost 50 on one date in November, 1933 (Cowland, 1934, Report to the Gezira Agricultural Res. Service, 107-125). In Israel during the 1930s and 1940s, Avidov (Ktavim 7:25-41) indicated that "the Tobacco White Fly caused considerable damage to vegetable crops..." and "Serious outbreaks of White Fly occurred in the following years: 1937, 1938/39, and 1940 and 1943". These historical examples, along with modern examples where *B. tabaci* occurs in low to moderate densities in systems with intensive insecticide usage (e. g. San Joaquin Valley, CA), help to make the case for a broader consideration of factors leading to outbreak populations of *B. tabaci*. A preoccupation with insecticide-related causes of whitefly outbreaks interferes with our ability to more fully comprehend other important factors contributing to whitefly outbreaks.

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**Research & Implementation Area:** Section F: Integrated and Areawide Pest Management Approaches, and Crop Management Systems.

**Dates Covered by the Report:** January 1997 - December 1997.

## Interaction of *Beauveria bassiana* with Various Fungicides Under Exposed Conditions

Fifty greenhouse grown poinsettia plants (*Euphorbia pulcherrima* (Wildenow) 'Freedom White') were infested with all stages of the silverleaf whitefly, *Bemisia argentifolii* Bellows and Perring. A total of 7 treatment combinations of BotaniGard (*Beauveria bassiana*) with various fungicides were compared using 6 replicates (plants) of each treatment. Treatments were: 1) Untreated Control, 2) BotaniGard ES alone (1 qt/100 gal); 3) BotaniGard ES + Kocide (0.75 lbs/100 gal); 4) BotaniGard ES + Mancozeb (1.2 qts./100 gal); 5) BotaniGard ES + Sulfur (6 hr burn, one night); 6) BotaniGard ES + Sulfur (6 hr burn, 3 nights); 7) BotaniGard ES + Bayleton (11 oz/275 gal). Fungicides were applied twice, two days before each of two BotaniGard treatments. Liquids were applied with a hand sprayer, and sulfur (Yellowstone® 99.9% S) was applied by vaporizing (Nivole® sulfur pot, Systems USA, Watsonville, CA) for 6 hours the nights preceding the other fungicide applications. Plants were treated with sulfur in a 113 $ft^2$ greenhouse for either three nights or one night before the first application of BotaniGard; the second sulfur application for both sulfur treatments was only for one night. BotaniGard was applied twice with a 7 day interval, two days after fungicide applications. Plants were treated with BotaniGard ES using a 2 gallon hand pump sprayer, approximately 25 psi. After treatments, plants were maintained outdoors under a light shade cloth.

Three days after treatment with BotaniGard, two leaves per plant were collected and pressed onto Benomyl-yeast agar plates and incubated for 24 hours. One hundred spores from each leaf press (12 counts per treatment) were rated as either germinated or not germinated and the percentage of spore germination was calculated. Six days after the last BotaniGard treatment, two leaves were collected from each plant and the number of live and dead immature whiteflies in a 4 cm diameter circle were counted on each leaf. Data were analyzed using ANOVA followed by LSD separation of means.

Kocide (64% and 61% germination, $1^{st}$ and $2^{nd}$ treatment respectively) and Mancozeb (6% and 10% germination) treatments resulted in significantly lower germination rates of *B. bassiana* spores compared to treatments of BotaniGard alone (89% and 81% germination) ($1^{st}$ treatment $P < 0.001$ ; df = 5, 30; $F = 77.31$, and $2^{nd}$ $P < 0.001$; df = 5,30; $F = 54.3$). Sulfur (79% and 69% germination) and Bayleton (87% and 70% germination) treatments did not decrease germination significantly. Mortality of whitefly immatures was significantly higher in all treatments (47-63% mortality) compared to controls (14% mortality). Mancozeb treatments had only about a 10 % germination rate of spores, yet still resulted in equivalent mortality rates compared to treatments that had 70-80% germination rates. This could indicate that *B. bassiana* spores at a 10% germination rate is just as effective as the 70-80% germination rates, or that the fungicide treatments themselves are directly contributing to the mortality of whitefly immatures. These results suggest that future mortality trials include treatments of fungicides alone for comparative purposes to determine the contribution of fungicides to insect mortality.

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**Dates Covered by the Report:** February 1997 - December 1997.

## Effects of UV-blocking Plastics on Insect Flight Behavior

Several new clear polyethylene film products, developed specifically for greenhouse use, have high UV-absorbing abilities while allowing 90-94% transmission of visible light. Field studies in Israel (Antignus, Y., M. Lapidot, N. Mor, R. Ben-Joseph, S. Cohen. 1996. Environmental Entomology 25: 919-924) reported significant reductions in whitefly (*Bemisia tabaci*), aphid (*Aphis gossypii*), and thrips (*Frankliniella occidentalis*) infestations in vegetable crops grown under ultraviolet (UV)-absorbent covered plastic tunnels compared to non UV-absorbent plastic. The presumed method of insect control is the removal of UV wavelengths that are necessary for proper orientation during flight (Antignus et al. 1996).

We conducted experiments examining the effects of similar plastics on insect flight behavior. Five high-UV-blocking products from 2 manufacturers, Klerkís Plastic Products (Richburg, SC), and DuraGreen Marketing USA, Inc. (Mount Dora, FL) were compared to their respective standard plastics. Insect species tested were the western flower thrips, *Frankliniella occidentalis* (Pergnde), and the silverleaf whitefly, *Bemisia argentifolii* Bellows and Perring.

All trials were conducted in a fallow field under natural solar radiation. In 'Choice' experiments, insects were released in black box at the center of two tunnels, and given a choice of entering either a tunnel covered with standard plastic, or a tunnel covered with UV-blocking plastic. The central release area was constructed out of black plastic with openings connected to two closed tunnels (total length of each tunnel approx. 18 x 18 in x 6 ft). Yellow sticky traps were placed inside the tunnels at fixed distances from the release area (2, 3, 4, 5, and 6 feet) to monitor flight activity inside the tunnels. In 'No-choice' experiments, insects were released at one end of a single tunnel (1.5 x 1.5 x 6 ft.) covered with one type of plastic, with four sticky traps placed 2, 3, 4, and 5 ft. from the release area. Eight hours after release, sticky traps were collected and counted. At least 4 replicate of each experiment were completed, and tunnel position was reversed for half the replicates to eliminate any effects of the direction of the sunlight. The relative percentage of insects caught at each trap distance was compared among treatments using ANOVA.

In choice experiments, significantly more insects were trapped in tunnels constructed of standard plastic films compared to UV-blocking plastic films. Yellow traps caught 90-98% of released thrips, and 85-95% of released whiteflies inside standard tunnels compared to UV-blocking tunnels. This indicates a distinct preference of both whiteflies and thrips to enter tunnels that transmit higher levels of UV light. In no-choice experiments, however, there was no significant difference in the number of whiteflies or thrips caught among types of plastic.

These results indicate that greenhouse plastics may have significant influence on the initial attraction of insects into greenhouse. It will be important to study these effects in more detail to understand why this occurs, and whether or not this phenomenon can be applied to management of insect pests in greenhouse crops.

**Investigator's Name(s):** P.C. Ellsworth[1],[2], S.E. Naranjo[3], S. Castle[3], J. Hagler[3], & T.J. Henneberry[3].

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**Research & Implementation Area:** Section F: Integrated and Areawide Pest Management Approaches, and Crop Management Systems.

**Dates Covered by the Report:** 1997.

## Development of Integrated Whitefly Management Strategies

As part of an overall program to examine and optimize whitefly management strategies within whole cotton production systems, we conducted an 8-acre, 11 treatment replicated field trial in Maricopa, AZ. We established a series of contrasted insecticide regimes (4), IGR sequences (2), IGR thresholds (2), and Lygus control states (2). This study marks the continuation of a line of investigation begun in 1995 and 1996 with 190 A and 178 A commercial-scale trials. The ultimate goal is to provide research-based recommendations to growers on the optimal use of whitefly control chemicals so as to minimize production system disruption, foster and understand the contribution of natural enemies, and mitigate whitefly resistance.

Whitefly population dynamics were measured weekly, and threshold level populations occurred approximately 3-4 weeks later than in 1996. Whitefly applications began on 29 July in all treatments. Lepidopteran pests were controlled through the use of Bt transgenic cotton (NuCOTN 33b) throughout the test; however, Lygus bugs reached threshold level densities in mid-July. Half of the plots in the IGR and the untreated check treatments were treated once on 25 July with Vydate C-LVR (1 lb ai/A), leaving the remaining halves of the plots for contrast. All applications were made by ground, broadcast at 15 GPA.

The number of sprays for whiteflies, cost, and yield were identical for both IGR sequences. There appeared to be no decided advantage to using Knack® or Applaud® first at the lower threshold where both IGRs were used; however, when only one IGR was used the cost of the Applaud regime was lower than the Knack® regime. By the last sampling date just prior to defoliation, whitefly populations were significantly higher in the higher threshold, IGR plots. Four sprays were made on the lower threshold IGR regimes, both IGRs followed by two non-pyrethroid sprays. Only two sprays were made on the higher threshold IGR regimes, one IGR followed by one non-pyrethroid spray-the second IGR was never re-triggered, because target threshold nymphal densities (1.5 large nymphs / disk) were never reached after the initial IGR spray. Five sprays were required for the conventional chemistry (non-IGR) 'IRM' treatment, three non-pyrethroid and two pyrethroid sprays. The cost of the IRM regime was equivalent to the lower threshold 2-IGR regimes, but significantly more than the higher threshold 1-IGR regimes. Yields were significantly different only in the Lygus control contrasts. Where one spray had been made for Lygus (before any of the whitefly sprays), there was a 0.3-0.5 bale / A relative yield increase over the untreated split-plots. Whitefly densities were higher, however, in the Lygus-treated areas on several dates, indicating the disruptive nature of Lygus insecticides on the system. Preliminary lint quality determinations showed no stickiness from the untreated check plots from late-season, hand-picked bolls, in spite of apparent sootiness. Post-harvest samples have yet to be analyzed.

In addition to the whitefly dynamics, yield, cost, and quality evaluations, we conducted a series of natural enemy evaluations and pyrethroid susceptibility bioassays on adult whiteflies. Three generations of immature whiteflies were subjected to partial life table analyses in situ, and the results are reported by Naranjo (this volume). Pyrethroid bioassays were conducted on three dates-pre-, during-, and post-spraying of whiteflies-using sticky yellow cards. The results reinforce our current IRM recommendations which encourage the first use of IGRs (Stage I), followed by non-pyrethroids (Stage II), and no more than two pyrethroid sprays (Stage III) season-long. These assays are reported by Castle (this volume). Also, the sublethal effects of the pesticides on predator foraging behavior were examined and the results are reported by Hagler (this volume).

This work was supported in part by grants to the senior author by Cotton Incorporated and the Western Region Pesticide Impact Assessment Program, as well as in-kind donations by various agricultural industries.

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**Research & Implementation Area:** Section F: Integrated and Areawide Pest Management Approaches, and Crop Management Systems.

**Dates Covered by the Report:** 1997.

## Integrated Cotton Management: Incorporating Whitefly Management & Multi-Pest IPM

The Integrated Cotton Management team is an interdisciplinary group of over 20 research & extension faculty. These faculty are housed in 9 county offices, 3 agricultural centers, and 6 campus departments. This group is responsible for the development and dissemination of cotton management recommendations for Arizona. Dissemination and teaching are via various educational vehicles: the Cotton Advisory System, organized delivery of Integrated Cotton Management Seminars and Workshops, several local and a Statewide Cotton Field Days, and Integrated Cotton Management Commercial-Scale Demonstrations.

### *Cotton Advisory System*

Arizona Cooperative Extension publishes weekly cotton advisories for 14 locations starting in February. Planting Date Advisories are used during the spring planting period and assist growers in determining risk of infestation by several pests (e.g., pink bollworm & whitefly) in relation to planting windows. Crop Development Advisories are produced once the crop is established. These 1-page reports include a site-specific, graphic representation of the growing season in relation to heat units, an insect update, a weather summary & 5-day forecast, & an agronomy update. Local county agents then add more information & distribute the advisories. Distribution is by mail, FAX, a campus-based electronic bulletin board system (AZMET BBS: 520–621–1197), and the World Wide Web (ag.arizona.edu/AZMET).

### *Integrated Cotton Management Seminars & Workshops*

ICM team members meet quarterly and plan for pre-, early-, in-, and late-season ICM seminars and workshops. These events are delivered to each of the 7 cotton-producing counties and feature campus- and Agricultural Center-based Specialists, County Faculty, related USDA, industry, regulatory and commodity-group representatives. Workshops have included live demonstrations in the field of plant-mapping techniques and sampling protocols for whitefly adults and large nymphs.

### *Statewide Cotton Field Day*

In addition to specialized, local cotton field days, each year the ICM team plans for a multi-disciplinary showcase of cotton research and extension at the Maricopa Agricultural Center. This event, which attracts 600–900 attendees from all segments of the the industry, features a bus tour through the 2000 A farm with stops at several experiments and discussion with project leaders, a symposium with featured speakers and discussion of major topics in the industry co-sponsored by the Arizona Cotton Growers Association, a poster paper and display session, and equipment displays.

### *Integrated Cotton Management Commercial-Scale Demonstration*

University recommendations are often offered in a singular fashion, assuming all other crop inputs are managed appropriately. Our aim is to integrate all components in a complete, "systems" approach (ICM). To better demonstrate the full integration and, most importantly, compatibility of all University recommendations, the ICM team has planned for and will implement commercial production of cotton on 40–60 A of the Demonstration Farm of the Maricopa Agricultural Center. While the system is made-up of dozens of recommendations, the three major components are: 1) optimizing the first cycle fruit set, 2) avoidance of late season insect pests, and 3) avoidance of inclement weather (monsoon). In addition to avoidance, the essence of whitefly management is: 1) Monitor/manage early season sources (e.g., prompt residue destruction, especially spring melons), 2) Sample adults & nymphs in cotton (at least 30 leaves per field), 3) Use insect growth regulators (IGRs) first [at 1 large visible nymph / disk (40% infested) AND 3–5 adults per leaf (40–57% infested with > 2 adults)], 4) Use each IGR once & in sequence in chronically infested areas, 5) Follow the insecticide resistance management (IRM) plan (e.g., limit, diversify & partition insecticide use; do not use pyrethroid combinations or any active ingredient more than twice for all pests), and 6) Conserve natural enemies by limiting broad-spectrum insecticides

**Investigator's Name(s):** Juli Gould[1], Larry Antilla[2], Mike Whitlow[2].

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**Research and Implementation Area**: Section F: Integrated and Areawide Pest Management Approaches, and Crop Management Systems.

**Dates Covered by the Report**: January 1996 - December 1996.

## Evaluation of the Compatibility between Insect Growth Regulators and Natural Enemies in Controlling Whitefly Populations

One of the obstacles to successful biological control of whiteflies in traditional agriculture has been the large amount of broad spectrum insecticides applied to control whiteflies and other pests. These insecticides kill natural enemies, and whitefly densities can quickly rebound after insecticide applications without the mortality induced by natural enemies. Recently, biorational insecticides such as insect growth regulators have become available as alternatives to broad spectrum pesticides. Many of these compounds seem to be less harmful to whitefly natural enemies than more traditional compounds. We hypothesized that many fewer applications would be necessary for whitefly control when using IGR's because natural enemies would be conserved. We tested this hypothesis by monitoring densities of natural enemies in ten cotton fields using conventional control techniques and ten fields using insect growth regulators. Because IGR's were available in Arizona in 1996 and not in California, we conducted this study along the Colorado River, with IGR sites in Arizona paired with non-IGR sites in California, and pink bollworm.

The pesticide use patterns were not as expected in the various areas. IGR's were indeed used in Arizona, however, other broad spectrum chemicals that could harm natural enemies were also applied. The number of pesticide applications was particularly large in Parker, where pink bollworm pressure was extremely high. At the beginning of the year only pheromone was used against pink bollworm in Parker, however as the season. Only two fields in Mojave received solely IGR's. With the exception of two fields in Mohave, the average number of pesticide applications against whiteflies was at least 5. As a result of the pesticide use patterns, the analysis was conducted for five areas: Blythe, Parker, Needles, Mohave (conventional insecticides: three fields), and Mohave-IGR (IGR's: two fields).

The density of immature whiteflies was lowest in the Mohave fields where only IGR's were applied. The first IGR spray in those fields occurred on 12 July and the pesticide was Knack® (pyriproxyfen). Applaud® (buprofezin) was applied 21 days later (2 Aug), not because sampling indicated it was necessary but because by law Applaud could be applied 21 days after Knack®. On 2 August, the number of whiteflies was low and declining, and it is likely that the second IGR application was unnecessary. Whiteflies in the conventionally treated fields in Mohave continued to increase to densities that were four times greater than in the IGR fields. Densities of whiteflies reached the greatest numbers in Needles, with a resurgence at the end of the season. The density of immature whiteflies continued to decline in the Mohave-IGR fields in spite of the fact that adult numbers were no different than in other areas. The variety of cotton planted cannot explain this difference; whiteflies do equally well on Bt cotton as on other varieties. Conservation of natural enemies could also account for this result.

From mid-July to mid-August, the number of predators collected in sweep nets was over four times greater in the Mohave-IGR fields than in the conventionally treated fields in Mohave or in Needles. The species that was most highly conserved in the IGR fields was the big-eyed bug, *Geocoris*. Densities of this species were never great in Blythe or Parker were insecticide applications began early. In Needles and Mohave, densities of *Geocoris* crashed after insecticide application commenced. *Geocoris* is an important whitefly predator, and the conservation of this species in the IGR fields could explain why whitefly densities remained low in these fields. Other predator species, such as the minute pirate bug (*Orius*), did not seem to be adversely affected by application of conventional insecticides.

**Investigator's Name(s):** Juli Gould[1], Larry Antilla[2], Mike Whitlow[2].

**Affiliation & Location**: [1]USDA-APHIS, Phoenix Plant Protection Center, [2]Arizona Cotton Research and Protection Council.

**Research and Implementation Area**: Section F: Integrated and Areawide Pest Management Approaches, and Crop Management Systems.

**Dates Covered by the Report**: January 1997 - December 1997.

## Integration of IPM and Biocontrol in a Multiple Cropping System

The silverleaf whitefly, *Bemisia argentifolii*, is a serious pest in many cropping systems in the desert southwest. Controlling this pest in any given crop or in a specific field is difficult, however, given the highly polyphagous nature of this insect and its high reproductive and migration capabilities. Utilizing the potential of natural enemies to control the whitefly is also problematic because insecticides used to control whiteflies and other pests usually also kill beneficial insects and disrupt natural control. Three of the major crops grown in the desert southwest (alfalfa, melons, and cotton) support whitefly populations during part of the year. Alfalfa is also a source of *Lygus* populations that can damage cotton. We propose that to effectively control whiteflies in cotton, we need to look at the entire agricultural system (both multiple crops and multiple pests) and utilize the most advanced technology that is the least disruptive to natural enemies. This includes: 1) early season inoculation of whitefly parasites in melons, 2) Bt cotton or pheromones for controlling pink bollworm and other Lepidoptera in cotton, and 3) controlling *Lygus* in alfalfa with egg parasites and leaving small strips of alfalfa on border edges to reduce the numbers migrating to cotton.

Our ultimate goal is to control pests in cotton fields in an economical manner that utilizes the action of natural enemies to the maximum extent. Because several key cotton pests come from alfalfa and melons, we plan to control these pests in the alternate crops to reduce migration into cotton. It is therefore crucial that the alfalfa and melon fields be right next to the cotton field so that any control we do in these fields has an effect on insects migrating into the study cotton field. There were 5 general locations where we conducted this research. At each location there was one group of fields (alfalfa, melons, cotton) treated under an IPM regime and one group of fields treated under a conventional regime.

We obtained the cooperation of several growers and pest control advisors for this project. The protocol has been followed and samples were collected weekly from alfalfa, melons, and cotton. We determined the number of whiteflies, Lygus, and natural enemies in the 30 fields. The final sample has been collected but data analysis is not yet complete.

**Investigator's Name(s):** R.L. Nichols.

**Affiliation & Location:** Cotton Incorporated, Raleigh, North Carolina.

**Research & Implementation Area:** Section F: Integrated and Areawide Pest Management Approaches, and Crop Management Systems.

**Dates Covered by the Report:** 1992–1997.

## Deployment of Insecticidal Modes of Action for Resistance Management

At the suggestion of the Chair, I opened a discussion at the progress review of the USDA-ARS Silverleaf Whitefly Five-Year National Research, Action, and Technology Transfer Plan.

Until recently, common hypotheses about insecticide resistance were that 1. resistance was inevitable, 2. resistance research was conducted primarily after the fact, and 3. pesticide labels were market-driven and need not be concerned with product longevity. The veracity and utility of these assumptions have been challenged by recent events in Arizona. A new perspective on pesticide management was initiated as a response to the emergence of the silverleaf whitefly as a dominating agricultural pest in low-desert, irrigated agriculture. In 1992, and again in 1995, the efficacy of the most commonly used insecticidal modes of action was severely reduced through heavy use. In many instances, whitefly populations were poorly controlled, and growers suffered burdensome financial losses. In 1996, through direct involvement of the Arizona Cotton Growers Association, in cooperation with the technical community and with basic manufacturers, two novel modes of action were introduced. A cornerstone of the revised system was limited use of each new product. In addition a specific, three-stage integrated resistance management (IRM) plan was developed by consensus. The fundamental precepts of the IRM were that 1. resistance is manageable, 2. strategies could be developed and implemented to extend the effective life of insecticides, and 3. planning for product longevity was a necessary part of the labeling process. Since growers pay the price of product development and resistance failures, they clearly have a stake in product labeling.

The whitefly is a multivoltine, polyphagous pest. Frequently, the same insecticides are used against the whitefly in several crops. Therefore successive generations of the same pest may be selected for resistance by the same biochemical mechanism in different crops at varying times of the year. In order to successfully manage resistance in polyphagous pests, it is necessary to utilize a comprehensive strategy for the conservation of modes of action across the entire agricultural system. The chloronicotinyl insecticides, and the juvenoid and chitin-synthesis inhibiting insect growth regulators are new chemistries to the U.S. The U.S. agricultural industry and the technical community have the challenge and opportunity to provide for long-term product efficacy for these new chemical families.

In order for product longevity to be assured, management programs that are technically feasible and economically profitable for both growers and manufacturers must be devised and labeled. Basic manufacturers are the chief source of new modes of action. Resistance management programs must guarantee continued incentives for product innovation. Accordingly movement to a new paradigm for resistance management concurrently mandates a new paradigm for pesticide marketing. Pesticidal modes of action may be viewed as scarce, common resources. It is probable that there are a finite number of modes of action that selectively disrupt pest life processes in a manner that is consistent with the protection of human health and the environment. Conservation of pesticidal modes of action is therefore a legitimate issue of public concern. In this regard, a valid goal for the public research community is achievement of sustainable integrated pest management programs based on product longevity.

Product longevity is a cost minimization goal for both growers and manufacturers. Product longevity can be abetted by the implementation of proactive resistance management at the time of market introduction. Manufacturers have the most direct responsibility for protecting the longevity of their products. Protection can be promoted through comprehensive product use planning and labeling strategies that conserve the efficacy of the modes of action. Positive results with Arizona whitefly IRM in 1996 and 1997 demonstrate that growers and manufacturers can cooperate with regulatory agencies to develop and implement product labeling strategies that provide for effective pest and resistance management.

## Research Summary
## Integrated and Areawide Pest Management Approaches, and Crop Management Systems

Compiled by: Peter C. Ellsworth

This section draws upon all sections in a synthetic process of systems development, integration, delivery and implementation. This summary will not attempt to bring together all the underlying components that support these systems and are reported by other sections. Due to the scale of study in this section and demand for integrated and areawide solutions by clientele, our section is also the focus for theoretical and philosophical examinations of whole agricultural systems.

**Philosophies**

This year we had two papers examining the issues of insecticides and their role(s) in the pest status of *Bemisia*. One (Castle) challenged the dogma that insecticides, through direct or indirect processes, are principally responsible for the rise in outbreak pest status of *Bemisia* around the world. Through a detailed historical perspective, Castle cast doubt on the assertions of past authors by presenting evidence from published accounts of *Bemisia* outbreaks in the 1920-1940s. While many of the points are arguable, Castle has succeeded in renewing interest and debate over the many interacting factors which may contribute to the outbreak pest status of *Bemisia*. While many are dedicated to the development of non-insecticidal-based control tactics, the bulk of success to date in many crops around the world has been, in fact, insecticide-dependent. Castle's work cautions us to consider the underlying factors that bring this pest to prominence and not to disqualify automatically those strategies which employ insecticides.

The value of insecticides and specifically novel modes of action, like the insect growth regulators (e.g., Applaud" & Knack" ) and chloronicotinyls, were further espoused by Nichols in his working discussion on deployment strategies for resistance management. Nichols pointed out that we currently have in our hands powerful and selective anti-whitefly agents which are or may soon become available in a variety of crops. Further, these crops are grown sympatrically in parts of the U.S. where *Bemisia* is a key pest year round. Nichols believes that these novel modes of action may be considered akin to scarce natural resources in need of active management. He detailed a multi-lateral success story that has occurred in Arizona cotton over the past two years where limited use of these IGRs is the cornerstone of a three-stage integrated resistance management plan. He has charged manufacturers of any novel mode of action with direct responsibility for protecting the longevity of these products and further the public research community with developing sustainable IPM plans for protecting these finite, selective, anti-insect resources. Nichols calls for technically feasible and economically viable (for both growers and manufacturers) management programs to be developed and labeled for these new products across all agricultural commodities.

**Development**

Crop- and/or population-level studies are necessary to fully understand and then develop integrated management systems for *Bemisia*. Crop-level interactions require the involvement of agronomists, horticulturists and others with expertise in plant systems. This area has not been vigorously explored in the past year; however, past accomplishments were noted (e.g., the impact of water stress on whitefly dynamics). Further work into identifying and evaluating the impact of various crop/cultural practices on whitefly dynamics is still needed.

Costa & Robb tested flight behavioral barriers as candidates for vegetable or greenhouse crops. They examined various plastics and their UV-blocking characteristics as potential barriers to *Bemisia* flight behavior in greenhouses. Isaacs et al. (Section E) also looked at *Bemisia* behaviors, but more specifically, host acceptance and oviposition behaviors of *Bemisia* on chemically-treated or untreated plants. They found that probing behavior was readily disrupted in adults alighting on plants systemically-treated with imidacloprid, but not when plants were treated foliarly with the same compound. Further work in this area could lead to additional insights into behavioral disruption for use in *Bemisia* management.

**Integration**

At the heart of IPM is the integration and organization of multiple control tactics into an ecologically sound strategy. Research in this area is limited, but progressing with most activity cited in cotton. Several reports center around a multi-institutional (USDA-ARS & Univ. Ariz.) examination of whole systems of whitefly management (F: Ellsworth et al.; D: Naranjo & Hagler, Hagler & Naranjo; C: Castle et al.; A: Naranjo et al.). Ellsworth et al. presented an overview and evaluation of the management system components (Bt cotton, IGRs, putative natural enemy conservation, & conventional insecticides). They showed that control tactics for other key pests, in this case *Lygus* bugs, can exacerbate whitefly management. Partial life table analyses (Naranjo et al.) support the hypothesis that *Lygus* controls disrupt whitefly dynamics via predator destruction. They also showed the comparative impact of whitefly insecticide regimes on *in situ* rates of predation and parasitism and suggest that parasitism plays a decidedly minor role compared to the overwhelming impact of indigenous predators. Naranjo & Hagler further noted the relative abundance of key groups of natural enemies in these

contrasted systems. The IGRs, especially pyriproxyfen, appear to be compatible with natural enemy conservation and biological control of *Bemisia*. Further, Castle et al. showed that IGR-based regimes preserve susceptibilities to the synergized pyrethroids compared to non-IGR-based regimes.

Costa looked at the compatibility of *Beauvaria bassiana*, a key entomopathogen of *Bemisia*, with various fungicides necessary for control of plant pathogens. This type of work is key to establishing integrated practices in the greenhouse and nursery industries where pesticides such as fungicides are used for the control of other pest problems. Costa found that there were fungicides that did not interfere with *Beauvaria* germination; however, even when one did interfere, similar mortality rates of *Bemisia* were still observed. Costa suggests that future work should include an examination of the direct effects of fungicides on *Bemisia* mortality. Gould et al. also looked at dual tactics (IGRs & natural enemies) and multiple crops (alfalfa, melons, cotton) in commercial systems in the southwest. Their focus was on preservation of natural enemies through careful selection and use of control tactics that were least disruptive to natural enemies in multiple crop - multiple pest systems.

Full integration of sampling with other key components of IPM such as thresholds, economics, etc., is crucial to the successful delivery and adoption of IPM. While past work in some systems (e.g., cotton & melons) has been substantial, relatively little work was reported this past year, especially in the area of sampling plans for new crops (1 paper on sampling in tomatoes). There has been continued work on integrating sampling plans for cotton with IGRs, thresholds, and decision-making. Ellsworth et al. (see above) examined re-treatment thresholds and decision-making for control of *Bemisia* with IGRs. Their findings suggest that relatively high re-treatment thresholds may be possible following the first IGR without economic losses in yield or quality. However, late season whitefly dynamics suggested that more conservative re-treatment thresholds that called for a second IGR protected against risk of late-season losses in quality, especially had the production system been carried later into the fall. Ellsworth et al. (not reported) also developed a binomial sampling plan for large nymphs in cotton and integrated this work with a refined large nymph threshold as part of a two-component threshold for IGR use. Work by Naranjo et al. (see above) may also lead to integration of natural enemy presence and abundance information into sampling and decision-making in cotton.

**Delivery & Implementation**

A large demonstration program was reported by Brazzle et al. in the San Joaquin Valley of California. While their focus was on cotton (and the preservation of cotton lint quality), their approach included all crops in a large area in Kern County (7500 A). Systematic sampling, attention to thresholds, timely use of IGRs, proper rotation of other chemistry, coupled with cultural controls and efficient crop management led to qualitatively better outcomes in the program areas when contrasted with conventionally-managed, uncoordinated areas. In Arizona cotton, Husman & Jech reported on a very large integrated whitefly management program (18,000 A). In this area of chronic whitefly problems, they implemented a sampling and thresholds-based strategy for whitefly management (1995-1997). In 1995, prior to the introduction of the IGRs, whitefly control was considered disastrous with as many as 12 applications required for whitefly control. In 1997 with the availability of the IGRs, control was considered successful with an average of 2.81 applications against whiteflies. While individual fields or growers may have failed to adopt recommendations fully, two thirds of the community used IGRs and overall averaged less than 0.5 pyrethroids for whiteflies (compared to ca. 6 in 1995). Bt cotton was also used, because many perceived that early, broad-spectrum sprays required in non-Bt cotton in prior years contributed to the outbreak status of whiteflies in their community.

The areawide programs cited above represent new initiatives to extend IPM information and recommendations to growers in California and Arizona. In addition, Brazzle et al. attempted to extend integrated crop management recommendations, especially for cotton, in their area. These included management of cotton for earliness and efficient defoliation of the crop. Other examples of ICM recommendations reflecting whitefly control guidelines were by Ellsworth & Silvertooth. They developed a full system of recommendations for a model site in Arizona and plan to implement these practices and guidelines on a large demonstration (ca. 50 A). Further work is needed in other crop systems and in other locales to fully integrate whitefly and IPM guidelines with ICM recommendations.

**Table F. Integrated and Areawide Pest Management Approaches, and Crop Management Systems.**

| Research Approaches[a] | Year 1 Goals Statement | Progress Achieved Yes | Progress Achieved No | Significance |
|---|---|---|---|---|
| **Development:** | | | | |
| **Study whitefly-crop interactions[b] as cultural components that affect population dynamics, e.g., water, nutrients, plant population, planting/termination/harvest dates, other farm practices, intercrop relationships.** | Identify potential beneficial or exacerbating farm practices or inputs for testing. | X but limited | | Only minor progress has been made on this approach (since last 5-yr review), & mainly in area-wide programs. This work is correlative, & little experimental work has been planned for or reported. Past work identified the potential or described the role of fertility status, water-stress & some other agronomic factors on *Bemisia* population dynamics. Conceptual discussion was presented on the role of pesticidal & non-pesticidal factors on *Bemisia* outbreaks. |
| **Develop behavioral barriers[b] to whitefly colonization and population development, e.g., mulches, trap crops, inter-cropping, row covers, etc.** | Review potential behavioral disrupters and evaluate as potential IPM components. | X | | Progress has been made in several areas:<br>• row covers and screens as physical barriers,<br>• mulches and oils as behavioral barriers,<br>• living mulches as behavioral barriers. |
| **Integration:** | | | | |
| **Develop Integrated Pest Management[c] systems using dual or multiple control tactics, e.g., cultural, biological, chemical, host plant resistance, etc.** | Identify candidate dual or multiple control tactic systems, e.g., IGRs and natural enemy conservation. | X | | Significant activity on this goal has occurred:<br>• Insect Growth Regulators & biological control in cotton (conservation)<br>• imidacloprid & other chemical control tactics & various forms of biological control, especially in vegetables<br>• studies of direct & indirect effects of chemical control on bio-control agents. |
| **Integrate sampling with other key components of IPM systems, e.g., thresholds, economics, decision-making, biological control, etc.** | Develop or modify sampling systems for new crops; integrate with thresholds and decision-making. | X | | Limited progress has been made in this area:<br>• *Bemisia* distributions have been examined in tomato,<br>• new binomial sampling system for large nymphs in cotton, & integration with thresholds for IGR decisions<br>• sampling & IGR re-treatment decisions tested in cotton. |

**Table F. Integrated and Areawide Pest Management Approaches, and Crop Management Systems. (Continued)**

| Research Approaches[a] | Year 1 Goals Statement | Progress Achieved Yes | No | Significance |
|---|---|---|---|---|
| **Delivery and Implementation:** | | | | |
| **Elevate single field/farm practices to areawide community-based contexts; develop methodology for installing and evaluating areawide control technologies and their impact.** | Identify agricultural communities amenable to areawide management; conduct thorough pre-implementation evaluation. | X | | Significant progress was made in this area mainly in cotton:<br>• areas dominated by cotton were identified in AZ & CA for implementation of cooperative programs.<br>• areas of melon and vegetable production were identified in TX for potential area-wide programs.<br>• area-wide sampling, & decision-making was the main focus of most programs; however, coordinated natural enemy releases were also conducted. |
| **Implement and deliver Integrated Pest Management and Integrated Crop Management systems or system components to clientele.** | Develop and distribute provisional IPM & ICM recommendations. | X | | Continued progress was made in this area:<br>• IPM recommendations were distributed AZ, CA, Mexico & FL; bilateral discussions between Brazil & U.S. took place.<br>• IPM & ICM guidelines were coordinated in AZ cotton. |

[a] See Tables A to E for additional complementary research.
[b] See Tables A for additional complementary research.
[c] See Tables E for additional complementary research.

# ADDENDUM

## Bibliography of

## *Bemisia tabaci* (Gennadius)
## &
## *Bemisia argentifolii* Bellows and Perring

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**George D. Butler, Jr.**
**Thomas J. Henneberry**

**January 1998**

## Appendix A. Bibliography of *Bemisia tabaci* (Gennadius) & *Bemisia argentifolii* Bellows and Perring

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In 1995 we published a bibliography of *Bemisia tabaci* (Gennadius) and *Bemisia argentifolii* Bellows & Perring (Butler et al. 1995). This bibliography was compiled from various sources including the current awareness literature service of the National Agricultural Library, Current Contents (Institute for Scientific Information), the two published bibliographies of Cock (CAB International), and the proceedings of several international conferences and symposia. It attempted to cover the world literature through the end of 1994. Addenda to this bibliography were published in 1996 (Naranjo et al. 1996) and 1997 ( Naranjo et al. 1997) covering new citations listed during 1996. This 3rd addendum includes citations listed during 1997.

We would like to alert users of this bibliography to several points. First, we have not attempted to abbreviate many of the names of non-US publications and have spelled out some names, especially USA state names, to assist students in other countries. Second, we have not been able to obtain copies of some of the citations and so could not verify spelling, scientific names, irregular punctuation, and accuracy of the location of the reference. We have tried to standardize as much as possible, but our references may not be exactly as given in the original publications.

The original bibliography and all addenda were produced using Pro-Cite 2.1.1 for DOS (Personal Bibliographic Software, Inc.). To simplify the distribution of electronic copies, we maintain the January 1998 addendum and the total bibliography (through January 1998). This permits those with the complete database from last year to update through the end of 1997 and those without any of the versions to obtain the entire bibliography. We offer several options for obtaining electronic copies. For those that send us a blank diskette and mailer, we will provide copies of the databases in Procite format (for those that have Procite software) word processor format (specify Word or WordPerfect) or ASCII text format. We can also provide the databases along with a runtime version of the Procite software. This runtime software will enable you to search and print the database. Finally, you can download any of the formats mentioned above from the Western Cotton Research Laboratory World-Wide-Web Homepage, **http://pwa.ars.usda.gov/wcrl/**.

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**Appendix B: Meeting Agenda**

## FIRST ANNUAL PROGRESS REVIEW OF THE FIVE-YEAR SILVERLEAF WHITEFLY RESEARCH, ACTION, AND TECHNOLOGY TRANSFER PLAN
### Agenda

**Monday, February 2, 1998**

| | | |
|---|---|---|
| 12:00 noon | Poster set-up begins (GOLD ROOM) | |

**Tuesday, February 3, 1998**

| | | |
|---|---|---|
| 7:00 a.m. | Registration (MEZZANINE LEVEL REGISTRATION AREA)<br>Continental Breakfast (PINCKNEY ROOM) | |

**PLENARY SESSION--INVITED PRESENTATIONS (COLONIAL BALLROOM)**

| | | |
|---|---|---|
| 8:00 a.m. | Welcome | Alvin Simmons and Nick Toscano |
| 8:20 a.m. | Charge to Conference | Tom J. Henneberry |
| 8:30 a.m. | *Polyol Synthesis as a Mechanism for Thermotolerance in Bemisia* | Michael Salvucci |
| 9:00 a.m | *An Update on the Status of Whitefly-Transmitted Geminiviruses: The Good, the Bad, and the Ugly* | Robert Gilbertson |
| 9:30 a.m. | *Understanding Insecticide Resistance in Bemisia* | Frank Byrne |
| 10:00 a.m. | Break | |
| 10:15 a.m. | *Biological Control of Bemisia argentifolii: Using Lifetables and Functional Response Assays to Determine Parasitoid Efficacy in Greenhouses* | Mark Hoddle |
| 10:45 a.m. | *Plant Resistance to Whiteflies: Lessons from the Past--Directions to the Future* | D. Michael Jackson |
| 11:15 a.m. | *Improved Areawide Whitefly Management through a Voluntary Industry/Extension Partnership* | Stephen H. Husman |
| 11:45 a.m. | *Impact of Silverleaf Whitefly on California Citrus* | Ted Batkin |
| 12:00 noon | Lunch | |
| 1:30 p.m. | Discussion--Continuation of National Meeting | Robert M. Faust, Tom J. Henneberry, Nick Toscano, and Thomas M. Perring |

**SECTION MEETINGS (COLONIAL BALLROOM)**

| | | |
|---|---|---|
| 2:00-5:00 | Sections A and F--10-minute presentations of submitted papers (see attached) | |
| 5:30 p.m. | Mixer and Poster Session (GOLD ROOM) | |

**Wednesday, February 4, 1998**

| | | |
|---|---|---|
| 7:00 a.m. | Continental Breakfast (PINCKNEY ROOM) | |
| 8:00-11:00 | Sections D and B--10-minute presentations of submitted papers (see attached) | |
| 11:00 a.m. | *Optional Tour*--U.S. Vegetable Laboratory (sign-in sheet available at registration desk) | |
| 12:00 noon | Lunch | |
| 2:00-5:00 | Sections C and E--10-minute presentations of submitted papers (see attached) | |

**Thursday, February 5, 1998**

| | | |
|---|---|---|
| 7:00 a.m. | Continental Breakfast (PINCKNEY ROOM) | |

**TECHNOLOGY TRANSFER SESSION (COLONIAL BALLROOM)**

| | | |
|---|---|---|
| 8:00 a.m. | Section A | Steve Naranjo |
| 8:30 a.m. | Section B | Robin Huettel |
| 9:00 a.m. | Section C | Phil Stansly |
| 9:30 a.m. | Section D | Charles Pickett |
| 10:00 a.m. | Break | |
| 10:15 a.m. | Section E | Eric Natwick and Alvin Simmons |
| 10:45 a.m. | Section F | Peter Ellsworth |
| 11:15 a.m. | Concluding Remarks | Thomas M. Perring |
| 11:30 a.m. | Adjourn | |
| 1:00 p.m. | Working Group Meeting (CALHOUN ROOM)<br>Immediately following the Working Group, the PPRC will meet. | Robert M. Faust |

**Section A: Biology, Ecology, and Population Dynamics**
**Co-Chairs: Jon Allen and Steve Naranjo**

*Polyol Metabolism in the Sweetpotato Whitefly*
Hendrix, D.L.

*Cloning and Sequencing of a cDNA Encoding the Whitefly Ketose Reductase*
Wolfe, G.R.

*Population Dynamics of Whiteflies on Wild Hosts in Israel*
Gerling, D.

*Sampling Protocol for SLWF on Tomato*
Perring, T.M. and C.A. Farrar

*Silverleaf Whiteflies' Attraction to White Fluorescent Light*
Chu, C.C. & T.J. Henneberry

*Impact of the Silverleaf Whitefly, Bemisia argentifolii, in Brazil*
de Oliveira, M.R.V.

**Section B: Viruses, Epidemiology, & Virus-Vector Interactions**
**Co-Chairs: Robin Huettel & Doug Maxwell**

*Feeding Behavior May Explain Why Nonpersistent Viruses are Transmitted Primarily by Aphids, Not Whiteflies*
Walker, G.P. & D.D. Johnson

**Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods**
**Co-Chairs: Tim Dennehy and Phil Stansly**

*It Seems the SLWF Insecticide Resistance is Present on Cotton in the Mexicali Valley, Mexico*
Lopez, R.L., & M.Q. Meza

*Use of Neem Products/Azadirachtin as Biorational Insecticides against Silverleaf Whiteflies for Insecticide Resistance Management Programs (IRM) in Cotton*
Akey, D.H. & T.J. Henneberry

*Management of Silverleaf Whitefly, Bemisia argentifolii, Using Biological Control Agents*
Seal, D.R. & R.T. McMillan

*Evaluation of Two Experimental Compounds from NOVARTIS Against Bemisia argentifolii*
Prabhaker, N., N.C. Toscano, D.S. Lawson & K. Jones

*Field Evaluation of Three Systemic Insecticides for Control of Bemisia argentifolii in Staked Tomato*
Stansly, P.A.

**Section D: Natural Enemy Ecology and Biological Control**
**Co-Chairs: Kevin Heinz and Charles Pickett**

*Effects of Natural Enemies on Whitefly Mortality in Cotton under Different Management Systems: Life Table Analysis*
Naranjo, S.E., P.C. Ellsworth, & J.W. Diehl

*A Simple Protein Marking ELISA to Monitor Parasitoid Dispersal*
Hagler, J. and C.G. Jackson

*Comparative Suitability of Two Bemisia Spp. as Hosts for Parasitoids*
Jones, W.A.

*Comparative Evaluation of Host Instar Suitability for the Parasitoids Eretmocerus mundus and Encarsia pergandiella*
Greenberg, S.M., W.A. Jones, & W.C. Warfield

*Biology, Ecology and Feeding Behavior of Semidalis sp., a Native Neuropteran Predator of Bemisia in the Southwestern Desert*
Hoelmer, K.A., J. Hagler, & C.G. Jackson

*Satellite DNAs as Identification Probes for Encarsia and Eretmocerus Wasps*
Heilmann, L.J.

*Demonstration of Biological Control Based IPM of Sweetpotato Whitefly*
Ciomperlik, M.A., J.A. Goolsby, T. Poprawski, and L.E. Wendel

*Augmentation of Parasitoids via Banker Plants*
Goolsby, J.A., M.A. Ciomperlik, & L.E. Wendel

*Silverleaf Whitefly and Parasite Releases in the San Joaquin Valley: An Update*
Pickett, C.H.

*Parasite Composition in Refuges during Four Years of Exotic Species Releases*
Roltsch, W.

**Section E: Host Plant Resistance, Physiological Disorders, and Host-Plant Interactions**
**Co-Chairs: Eric Natwick and Alvin Simmons**

*Fate of Immature Bemisia on Adaxial Leaf Surface of Some Vegetables*
Simmons, A.M.

*Host Evaluation Behaviors of Bemisia and Their Modification by Systemically-Treated Imidacloprid*
Isaacs, R.

*The Tomato Defense Response to Silverleaf Whitefly*
Puthoff, D., A. Cooper, T.M. Perring, & L. Walling

*Impact of SLWF Feeding on Tomato Fruit Physiology*
Perring, T.M., B. Moore & C.S. LeVesque

*Genes Involved in Silverleaf Whitefly Induced Squash Leaf Silvering*
van de Ven, M., C.S. LeVesque, A. Cooper, T.M. Perring & L. Walling

*Glabrous Leaf Melon: A Source of Host Plant Resistance to Bemisia*
Riley, D.G. & D. Wolff

*Silverleaf Whitefly and Cotton Leaf Crumple Resistance Screening in Upland Cotton*
Natwick, E.

**Section F: Integrated and Areawide Pest Management Approaches, and Crop Management Systems**
**Co-Chairs: Peter Ellsworth and John Norman**

*Silverleaf Whitefly in the Southern San Joaquin Valley: An Areawide Management Project in Progress*
Brazzle, J.R.

*Taking a Close Look at the Whole System, Whiteflies in Arizona Cotton*
Ellsworth, P.C., S.E. Naranjo, S. Castle, J. Hagler, & T.J. Henneberry

*Primary Pest or Synthetically Induced? The Role of Insecticides and Other Factors in the Pest Status of Bemisia tabaci*
Castle, S.

*Deployment of Insecticidal Modes of Action for Resistance Management: A Working Discussion*
Nichols, R.L.

**Appendix C: List of Registered Meeting Participants**

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## Appendix D. Minutes of the Silverleaf Whitefly Working Group Meeting

### Minutes of the Silverleaf Whitefly (SLWF) Working Group Meeting

February 5, 1998
The Francis Marion Hotel, Calhoun Room
Charleston, SC
1:00-2:00 p.m.

**Introductory Remarks**
The meeting was called to order by Robert Faust. He distributed an attendance sheet and discussed guidelines for the Working Group meeting and reviewed the agenda. Attendees were requested to introduce themselves and state their affiliation. He also distributed several handouts, including a Synopsis of Group Responsibilities and a USDA Sweetpotato Whitefly Research Education and Implementation Coordinating Group Membership List. Dr. Faust then reviewed the roles and responsibilities of the Working Group, Program Planning and Review Committee, section co-chairs, and the USDA Silverleaf Whitefly Research, Education and Implementation Coordinating Group. He requested that the synopsis of the various group responsibilities be included as a part of the SLWF Working Group minutes. Dr. Faust mentioned that a question had been raised last year regarding the need to maintain the working group. The group decided that this working group provides an open forum for the meeting process as well as an opportunity to critique the meeting and make suggestions to the PPRC, and therefore should be continued.

**Report of Meeting Attendance**
In attendance this year there were 86 registrants including the working staff. Foreign visitors were from Brazil (3), Trinidad (1), Israel (1), Dominican Republic (1), and Ireland (1).

**Program Brochures**
Sorrell Brown, Information Development Expanding Awareness Coordinator, Iowa State University, Cooperative Extension Service, Ames, IA, discussed a planned brochure that would serve as a partnership process document for the group's consideration. Tom Perring, UC Riverside, suggested that the recently completed 5-year plan technology transfer brochure be handed out in tandem with her brochure. She will match the colors and remove any duplicated information. Dr. Naranjo indicated that the picture of the whitefly on the cover needs to be changed to a silverleaf whitefly photograph.

**Working Group Critique of Workshop and Suggestions for the PPRC**
Dr. Faust stated that there is a need for short status reports, including economic losses resulting from SLWF infestations, from each state in future meeting plenary sessions. This could become part of the formal program report. Peter Ellsworth suggested a matrix for each crop in each state indicating percent infestation, crop losses, etc.

Tom Perring suggested that the annual meetings be changed to start on Sundays. Airline travel is less expensive if the travel day is Saturday and hotels are generally more flexible. This would mean that the PPRC would meet on Sunday morning, registration would be conducted at noon on Sunday and the plenary session would begin on Sunday afternoon.

Ian Wedderspoon liked the lack of concurrent sessions that allowed attendance in all sessions.

**International Activities**
Dr. Faust discussed the upcoming International Workshop on Bemisia and Geminiviruses in San Juan, Puerto Rico, 7-12 June 1998.

Dr. Ellsworth mentioned the International Workshop on Management and Control of *Bemisia tabaci* Species Complex meeting in Brazil, November 4-6, 1997. There are plans to hold an annual meeting beginning in March 1999.

**USDA SPW Research, Education and Implementation Coordinating Group: Membership Changes/Issues**
Nick Toscano will remain as a member.

**Other Business**
Ian Wedderspoon indicated that the technology transfer section of the five-year plan, summaries, and the new plan from the 1997 publication should be extracted as a separate document and published as a condensed version of the document for more general distribution (abstracts would not be included). This separate document would target extension agents, industry outlets, and universities. Dr. Wedderspoon agreed to provide a mailing list to Dr. Faust. Dr. Faust will discuss the possibility with the ARS Information Staff.

**Deadlines for the 1998 Progress Review Report:**
A deadline of February 20, 1998, was set for receipt of all corrected and/or additional abstracts, technology transfer/progress review summaries and year 1 tables for the 1998 Progress Review and Technology Transfer Report.

Information should be sent to:

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Lisa Arth requested that the information listed above be transmitted either on disk with a hard copy or via-e-mail with a hard copy in both word processing and text formats.

The minutes for the Working Group meeting will be transcribed by Marla Lawrence and then sent to Dr. Faust for review. The minutes will be included as an Appendix in the 1998 SLWF Progress Review and Technology Transfer Report.

Dr. Faust adjourned the Working Group meeting at approximately 2:00 p.m.

Respectfully submitted,

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Enclosures:

- SLWF Working Group Meeting Attendees
- Synopsis of Group Roles and Responsibilities
- SLWF Working Group Agenda
- USDA SLWF Research, Education and Implementation Coordinating Group Membership

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**Silverleaf Whitefly Program**
**Synopsis of Group Responsibilities**

- Silverleaf Whitefly (SLWF) Working Group

  - Critiquing the annual progress review;
  - Advising the Program Planning & Review Committee (PPRC) on emerging program issues, as needed;
  - Serving as a conduit for communication with the USDA SLWF Coordinating Group.

  Membership: Open to all interested parties.

- Program Planning and Review Committee (PPRC)

  - Detailed planning and structure of the annual progress review;
  - Creating the agenda for the progress review;
  - Assigning local arrangements responsibilities;
  - Establishing deadlines;
  - Preparing review materials;
  - Appointing section chairs with SLWF Working Group input;
  - Setting meeting objectives;
  - Finalizing the progress review report for publication;
  - Meeting at least once before each annual progress review, and then again after the review.

  Membership: Review coordinators, section chairs, local arrangements personnel, an advisory representative from the USDA SLWF Coordinating Group and the SLWF Working Group.

- Section Co-Chairs

  - Serving on the PPRC and SLWF Working Group;
  - Arranging section papers;
  - Setting section goals prior to the annual review;
  - Leading section sessions at the annual progress review;
  - Ensuring deadlines are met by meeting participants;
  - Preparing progress summaries and tables each year;
  - Recommending co-chair replacements;
  - Other related responsibilities as needed by review coordinators.

- USDA Silverleaf Whitefly Research, Education and Implementation Coordinating Group

  - Serve as the pipeline between administrators/legislators and the researchers.

  Membership: 2 members from ARS, 2 members from APHIS, 2 members from CSREES, 1 representative from a State Agricultural Experiment Station/Land Grant University.

Silverleaf Whitefly Working Group Meeting
February 5, 1998
Charleston, South Carolina
1:00 - 3:00 p.m.
Robert M. Faust, ARS-NPS, Presiding

**AGENDA**

| | |
|---|---|
| • Introductory Remarks/Old Business | R. Faust |
| • Report of Meeting Attendance | L. Arth |
| • Program Brochures | Perring/Kopp/Faust/Group |
| • Working Group Critique of Workshop & Suggestions for the PPRC | Group |
| • International Activities | Group |
| • USDA SPW Research, Education and Implementation Coordinating Group: Membership Changes/Issues | Faust/Kopp |
| • Other Items | Group |
| • Adjourn | |

**USDA Sweetpotato Whitefly Research**
Education and Implementation Coordinating Group

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**Appendix E. Minutes of the Program Planning Review Committee**

Minutes
PPRC Meeting
Francis Marion Hotel, Calhoun Room
2/2/98

Meeting was chaired by T. J. Henneberry and N. C. Toscano. PPRC members in attendance were:

| | | |
|---|---|---|
| Lisa Arth | Robert Faust | Cindy Giorgio |
| Robin Huettel | Marla Lawrence | Steve Naranjo |
| Tom Perring | Alvin Simmons | Phil Stansly |

Dr. Henneberry discussed the format for opening the meeting and introduction of invited plenary speakers. He also suggested that section chairs get together and develop a format for conducting the sessions.

The essentials for each section were:

1. Development of the year 1 progress review tables and significance statements for each research approach.

2. Review of plan priority tables and approaches and any suggested changes.

3. Development of summary statements of highlights for each section. These statements replaced the technology transfer statements for 1997, since discussions within the group suggest no new major developments since the last compilation of technology transfer.

4. The deadline for all material submitted to Lisa Arth was February 20, 1998.

Several PPRC members indicated that they had been asked to review the issue regarding the desire of the meeting attendees to continue the Research and Action Plan Reviews on an annual basis. Dr. Henneberry led a discussion regarding the reasons why the subject had resurfaced after last year's survey which suggested a majority of the people responding to the questionnaire wanted to continue on an annual meeting basis.

Declining meeting attendance and the development of independent groups such as the Sticky Cotton Action Team and the Resistance Management Working Group were suggested as indications that the Research and Action Plan was not serving all the needs of researchers. Also, there is an International Workshop on *Bemisia* and Geminiviruses in San Juan, Puerto Rico in the month of June 1998.

Suggested modifications of the current annual meeting schedule were to (1) regionalize the meeting--regional group meetings separate with some cross interaction by invitation, (2) meeting every other year, and (3) change the meeting format to broaden and cover other interest groups. No consensus was reached. However, the PPRC placed the subject on the agenda for discussion at the plenary session on Tuesday afternoon.

Drs. Henneberry and Toscano have served for 6 years as program chairs for the annual review. They asked for an expression of interest from the group or suggestions for people who might be interested in accepting the assignment for next year and possibly future annual review meetings. There were no volunteers.

Minutes
PPRC Meeting
Francis Marion Hotel, Calhoun Room
2/5/98

Meeting was chaired by T. J. Henneberry and N. C. Toscano. Members in attendance were:

| | | |
|---|---|---|
| Lisa Arth | James Brazzle | Peter Ellsworth |
| Robert Faust | Cindy Giorgio | Robin Huettel |
| Marla Lawrence | Steve Naranjo | Tom Perring |
| Charlie Pickett | Alvin Simmons | Phil Stansly |

The results of the discussion at the 2/3/987 plenary session regarding the desire of the group to meeting annually to review 5-year plan were briefly reviewed. The meeting attendees were overwhelmingly in favor of continuing the meting on an annual basis. The justifications and needs were very much the same as those of the respondents to the questionnaire addressing the same issue in 1996.

Dr. Henneberry again repeated the deadline for abstracts, summaries, and progress review tables as February 20, 1998.

Between the time of the 2/2/98 PPRC meeting and the 2/5/98 meeting, Dr. Tom Perring, UC Riverside and Dr. Walker Jones, ARS, Weslaco, TX volunteered an interest and commitment to serve as program chairs for the 1999 Annual Progress Review.

Drs. Henneberry and Toscano turned the meeting over to Dr. Perring for information, discussion and planning for the event.

Dr. Perring discussed several possible meeting sites. Suggested were:

1. Albuquerque, NM
2. San Diego, CA or Southern CA
3. San Antonio, TX

Dates suggested were January 30th – travel, meeting January 31st – Sunday through Wednesday

The subject was left at this point with a decision forthcoming after inquiries into available facilities, transportation access, and other considerations at each location.

It was recommended that registration fees be raised for the next progress review.

The group discussed possible expanded poster sessions and focus groups of 1/2 day in areas of high interest, possibly a program of headliner research outside of section structures.

Dr. Perring announced the following as section chairs for the 1999 meeting:

| | | |
|---|---|---|
| Section A | Steve Naranjo | Rufus Isaacs |
| Section B | Robin Huettel | Bob Gilbertson |
| Section C | Phil Stansly | James Brazzle |
| Section D | Charlie Pickett | James Hagler |
| Section E | Alvin Simmons | Greg Walker |
| Section F | Peter Ellsworth | Steve Castle |

Dr. Henneberry announced that the finalization of the proceedings for this year's (1998) review and the entire meeting proceeding's publication in the future will be handled by the Western Cotton Research Laboratory. For next year, abstracts for each section will be sent to co-chairs. There will not be a prepublication distributed at the meeting.

The program chairs will have the responsibility of sending out all meeting notices, deadlines, and meeting organizational material.

## Five-Year National Research and Action Plan Priority Tables, Research Needs, and Yearly Goals (1997-2001)

### Table A. Biology, Ecology, and Population Dynamics

| Approaches/Goals | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| **Determine life cycle vulnerabilities (life tables)[a], population development and natural mortality factors, natural enemies on major crops, urban plantings, weeds and predict overwintering potential.** | Whitefly and natural enemy sampling in cultivated crops, urban planting and weed hosts. | Determine potential of intercrop weed host & urban planting, movement of whiteflies and natural enemies. | Identify potential low population manipulation on vital host links for survival. | Initiate studies to manipulate host sequences to determine potential influence on whitefly population. | Continue 4 and finalize analysis of the potential of habitat modification as a management tool. |
| **Develop sampling methodology, action and[b,c] economic thresholds for all major crops. Sampling methods and thresholds modified in light of natural enemy levels and existing management strategies.** | Initiate whitefly to identify spatial and temporal distributions in major cultivated crops. | Analysis and identification of needed additional sampling research to develop appropriate sampling protocol. | Validate and refine sampling methods. | Implement sampling protocols through cooperative extension outlets and other technology transfer methods. | Finalization, implementation and use in IPM systems. |
| **Develop population models to describe and predict whitefly population growth and spatial and temporal distribution. Develop simple day-degree sub-models for estimating phenology and temporal patterns of whitefly, natural enemies and host crops.** | Summarize whitefly biology, ecology and plant phenology to identify whitefly host plant interfaces. | Begin model development to include all biological and plant phenology data in simulation development. | Provide model simulation of whitefly populations and multiple cropping systems. | Identify weak points and needed information to improve model simulations. | Validate and expand effort to provide predictive models capabilities for whitefly population development and crop interfaces. |
| **Develop sampling methods for quality of cotton lint, vegetables and other commodities.** | Initiate sampling of seed cotton in the field during the season, at harvest, after picking, moduling and ginning. | Based on 1, expand and repeat sampling protocols as described. | Develop sampling protocol for field and harvest and processing sampling and determine interrelationships. | Extend sampling protocols to textile mill and verify field findings in relation to mill problems. | Modify, refine and complete sticky cotton sampling protocols from the field to the mill. |
| **Quantify whitefly and natural enemy dispersals and contribution to population dynamics.** | Review and analyze existing knowledge of whitefly dispersal. | Validate times of whitefly dispersal, environmental factors and identify modifying factors. | Determine proportion of whitefly population that are migratory and their reproductive potential. | Quantify the role of dispersal in population dynamics on different crop systems. | Formulate theory for manipulating and/or using dispersal as a tool in IPM. |

**Table A. Biology, Ecology, and Population Dynamics**

| Approaches/Goals | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| **Define mating behavior, reproductive isolation, species, biotypes.** | Initiate studies on mating, oviposition and other behavior. | Define interspecies interbiotype mating interactions. | Define factors involved in mating, cues, feedback mechanisms, etc. | Develop potential methods of utilizing behavioral information in management strategies. | Review, summarize and propose additional needed research. |
| **Validate *Bemisia* taxa morphology, genetic, biochemical, and biology characteristics.** | Continue examination of *Bemisia* sp. for distinct morphological character differences. | Develop genetic molecular level and acceptable species level separation. | Discuss results, plan additional research, arrive at a consensus decision. | Publish verification of new species or other appropriate taxa. | ---------- |
| **Define role of endosymbionts in metabolism, host adaptation, nutrition and survival.** | Identify endosymbionts in whitefly. | Determine role of endosymbionts in whitefly biological functioning. | Determine potential for manipulating, interfering with or inhibiting endosymbiont function. | Determine associated enzymes and/or other endosymbionts and whitefly relationships. | Summarize and implement findings with suggestion for additional research. |
| **Develop whitefly artificial diets and natural enemy mass-rearing.** | Identify whitefly nutritional components in plant tissue. | Develop whitefly artificial feeding systems. | Conduct addition, deletion studies to identify essential nutritional needs. | Evaluate developed diets on whitefly fecundity/longevity biology, behavioral characteristics. | Develop whitefly rearing system and adapt for production of natural enemies. |

[a] Natural enemy research complements from Section D, see Table D.
[b] Action and economic thresholds also apply in Section C, see Table C.
[c] Sampling technology applicable to all other sections, see Tables B to F.

**Table B. Viruses, Epidemiology, and Virus-Vector Interactions**

| Approaches/Goals | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| **Identification and characterization of new or emerging whitefly-transmitted viruses and strains** | Monitor crops for presence of whitefly-transmitted diseases, and determine relative disease incidence. Begin virus identification and strain differentiation. | Virus identification and characterization. Develop methods for identifying causal agents and for tracking viruses and strains using molecular methods. | Continue etiological studies and virus characterization. Apply molecular diagnostics to virus identification and evaluation of disease incidence and virus distribution. | Continue etiological studies and virus characterization efforts. Apply molecular diagnostics to virus identification and evaluation of disease incidence and virus distribution. | Summarize and review results. Determine areas of new research. |
| **Molecular epidemiology: identification of economic viruses, host plants, and reservoirs, and determination of geographic distribution of viruses.** | Monitor and identify host plants, virus reservoirs in affected areas. Linkages to diagnostic methods for virus ID and tracking. | Continue field studies. Determine economic input of diseases on crop production and associated losses. | Establish geographic distribution of viruses and identify sources of inoculum. Assess role of alternative host virus reservoirs on spread of diseases. | Identify and characterize virus involvement in disease establishment and spread. Assess potential methods of reducing virus reservoirs as a method of reducing disease. | Review and make recommendations for further research and potential implementation of results. |
| **Virus-vector interactions, factors affecting virus transmission, and basis for virus-vector specificity; determination of endosymbiont involvement in whitefly-mediated transmission** | Initiate studies on virus-vector interactions and on basis for the specificity of whitefly-mediated geminivirus transmission. | Determine specific cellular and molecular factors involved in virus transmission. Study role of endosymbionts in virus acquisition and transmission. | Continue studies in progress to determine specific factors involved in virus transmission, and the role of endosymbionts in virus acquisition and transmission. | Continue virus-vector interactions studies toward the development of approaches for disease control. | Summarize findings and suggest new research needs; implementation of existing knowledge. |
| **Strategies to reduce virus spread by management of cropping systems, reduced transmission frequencies, and other potentially effective approaches.** | Develop approaches to managing cropping systems to reduce vector densities to decrease transmission frequency and inoculum sources, taking into account weed and crop reservoirs in disease incidence and distribution. | Continue studies of management approaches for disease abatement. Interdisciplinary studies in conjunction with whitefly control methods in Sections B and C. | Continue studies of management approaches for disease abatement. Focus on interdisciplinary studies in conjunction with whitefly control methods in Sections B and C. | Evaluate strategies for crop management and impact on disease epidemiology. | Evaluate approaches and identify areas of future research for disease control by management of cropping systems. Linkages with IPM approaches. |

**Table B. Viruses, Epidemiology, and Virus-Vector Interactions (continued)**

| Approaches/Goals | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| **Control of virus diseases: development of virus resistant germplasm through conventional and engineered/molecular approaches. Define prospective strategies for selecting candidate viruses, identifying specific virus diseases to target, and prioritize specific crops and cultivars for protection approaches.** | Define strategies for resistance efforts. Identify target viruses. Identify germplasm with virus resistance. Initiate efforts toward defining prospective engineered resistance strategies. Identify candidate crops and recipient cultivars. | Continue to define suitable strategies for determining target viruses. Isolate and characterize virus-resistant germplasm. Continue work toward engineered resistance in target crops and selected viruses. | Further identification of resistant germplasm and develop new methods of incorporating resistance into crop plants. Evaluate resistance strategies with respect to broad spectrum or virus-specific protection. | Continue development of resistant varieties. Evaluate resistance strategies with respect to broad spectrum or virus-specific protection. Define mechanisms of resistance. | Evaluate resistant plants in greenhouse and field experimentation, and identify additional research. Molecular-based monitoring of transgenes in environment. |
| **Pursue specific genetic and biological basis for variability in whitefly biotypes, strains, and species; determine impact of different genotypes/phenotypes on whitefly-mediated transmission and on the epidemiology of virus diseases.** | Identify differences in species, strains and biotypes with respect to transmission, host range, mating compatibilities, molecular variability, and map the biogeographic distribution of distinct types within the *B. tabaci* species complex. | Continue to study differences in species/ strains/biotypes with respect to transmission, host range, mating compatibilities, molecular variability. Determine molecular basis of observed variability in biological, molecular, & genetic terms. Infer molecular phylogenies from molecular markers. | Continue with work from previous years. Study impact of biotypes, strains, and species differences in the disease spread, crop damage, and specific control measures to reduce whitefly vector populations. Linkages with biological and chemical control sections. | Identify potential factors related to specific genetic and biological variability that may be manipulated to reduce disease spread. Develop molecular approaches to track biotypes, strains, and species relative to disease spread, based on differential molecular markers. | Summarize results, identify new research needs and make recommendations for implementation or expansion of research. |

**Table C. Chemical Control, Biopesticides , Resistance Management, and Application Methods**

| Approaches/Goals | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| **Improve insecticide efficacy:** | | | | | |
| • **Develop, test, and assist in the registration of insecticides, biorationals, and natural products.** | Develop new chemistries and natural products. Develop improved techniques for evaluating efficacy of insecticides. Support registration of desirable new products by providing information to regulatory agencies. | Same as Year 1. Determine new modes of action of effective materials. Elucidate biochemical pathways of synthesis and degradation of natural products. | Same as Year 2. Evaluate the potential for transforming plants with natural product genes. | Same as Year 3. | Same as Year 4. |
| • **Develop improved methods of application including formulation and delivery of materials to improve control.** | Develop spray systems for better underleaf coverage. Evaluate rates, timing, placement in relation to efficacy. Consider formulation, UV protectants, and other means to improve efficacy. Develop improved methods to evaluate application efficacy. Field test under commercial conditions for technology transfer. | Same as Year 1. | Same as Year 2. | Same as Year 3. | Same as Year 4. |
| **Conserve insecticide efficacy:** | | | | | |
| • **Relate action thresholds to insecticide usage patterns.** | Refine action thresholds based on insecticide efficacy and input from other control strategies. | Same as Year 1. | Same as Year 2. | Same as Year 3. | Same as Year 4. Summarize and recommend in IPM systems. |

**Table C. Chemical Control, Biopesticides , Resistance Management, and Application Methods (continued)**

| Approaches/Goals | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| • **Elucidate the role of genetic, biochemical and ecological factors leading to insecticide resistance.** | Establish whitefly strains resistant and susceptible to various classes of insecticide. Conduct studies to determine the genetics and biochemistry of resistance and cross resistance to different classes of insecticide. | Same as Year 1. Evaluate the role of refuge habitats (weeds, tolerant crops, urban areas) to assure input of susceptible genes in whitefly population. | Conduct studies to determine the genetics and biochemistry of resistance and cross resistance to different classes of insecticide. Evaluate the role of refuge habitats (weeds, tolerant crops, urban areas) to assure input of susceptible genes in whitefly population. Evaluate the influence of host plant on susceptibility to insecticides. | Same as Year 3. | Same as Year 4. |
| **Improve insecticide efficacy:** | | | | | |
| **Improve techniques for monitoring resistance.** | Establish baseline data on toxogenic responses of whitefly populations to new insecticides. | Same as Year 1. Expand comparative studies of resistance levels in diverse agro-ecosystems. Evaluate relationship between monitoring results and field efficacy. | Same as Year 2. Summarize, analyze, and produce standardized comparable monitoring systems. | Same as Year 3. Develop standard systems for general use including user friendly techniques to assist growers and extension agents to evaluate susceptibility of whitefly populations to commonly used insecticides. | Same as Year 4. |

**Table C. Chemical Control, Biopesticides , Resistance Management, and Application Methods (continued)**

| Approaches/Goals | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| **Develop, evaluate and refine resistance management systems** | Evaluate the effects of mixtures and rotations of new and old chemistries to mitigate selection for resistance. | Same as Year 1. Develop methods to evaluate and augment the beneficial influence of refuges as sources of susceptible genes to the population pool. | Same as Year 2. Develop criteria for integration of successful strategies in agricultural systems. Field test resistance management systems as long range components of successful IPM. | Same as Year 3. | Same as Year 4. Technology transfer. |
| **Integrate chemical control with other tactics.** | Evaluate selectivity of synthetic insecticides and natural products to key whitefly natural enemies. | Same as Year 1. Test compatibility of biological control with selective synthetic or natural product insecticides as required. | Same as Year 2. Integrate systems with host plant resistance and cultural controls. | Test compatibility of biological control with selective synthetic or natural product insecticides as required. Integrate systems with host plant resistance and cultural controls. | Integrate systems with host plant resistance and cultural controls. Summarization and technology transfer. |

[a] See Table A for complementary research on thresholds.
[a] See Table B for complementary research on virus/vector interactions.
[a] See Table D for complementary research on biological control.
[b] See Tables E and F for complementary research on systems management.

**Table D. Natural Enemy Ecology and Biological Control**

| Approaches/Goals[a] | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| **Natural control and conservation:** | | | | | |
| • **Develop natural enemy conservation practices to reduce mortality to indigenous and introduced natural enemies.** | Conduct life table analyses of indigenous and introduced natural enemies to identify key mortality factors of natural enemy populations. | Identify the spatial scale upon which the key mortality agents are acting. | Conduct manipulative experiments to evaluate the impact of each natural enemy mortality agent on whitefly suppression. | Conduct a feasibility study and economic assessment of altered crop management practices that may enhance the impact of indigenous natural enemies. | Develop and evaluate area wide programs to facilitate full implementation. |
| • **Evaluate potential of alternate plants it act as in-field refuges or insectaries for natural enemies.** | Identify potential plants for natural enemy population development and assess risks of these plants to foster additional pest problems. | Determine refugia plant phenology in relation to cultivated crop phenology. | Conduct field tests to assess whether refuges act of natural enemy and whitefly sinks or sources to adjacent cropping systems. | Conduct field tests to evaluate spacing of refuges necessary to achieve satisfactory whitefly suppression. | Conduct a feasibility study and economic assessment of alternate plantings in terms of an entire crop management program. |
| • **Assess cues used by natural enemies to locate whitefly to identify potential methods for enhancing natural enemy activity.** | Conduct laboratory tests to identify cues used by natural enemies to locate and attack whitefly. | Determine potential methods for manipulating cues as part of a whitefly management program. | Conduct small scale trials to enhance whitefly suppression by manipulating natural enemy location and attack of whitefly. | Conduct large scale field trials and evaluate product development for commercial investment as necessary. | Transfer technology (as needed) to commercial interests for full implementation. |
| **Augmentation of natural enemies:** | | | | | |
| • **Develop natural enemy mass-rearing systems.** | Identify natural enemies with the highest potential for controlling whitefly in key cropping systems. | Determine nutritional, physiological, and ecological requirements for mass-rearing. | Develop rearing systems on selected hosts and on artificial diets. Determine economic feasibility of the procedure. | Evaluate rearing system effects on natural enemy life history characteristics, behavior, and ability to suppress whitefly populations. | Facilitate transfer of mass-rearing technology to commercial interests as necessary. |

**Table D. Natural Enemy Ecology and Biological Control (continued)**

| Approaches/Goals[a] | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| **Importation biological control:** | | | | | |
| • **Develop release technologies to maximize the effectiveness of mass-reared natural enemies in the field.** | Identify natural enemies with the highest potential for controlling whitefly in key cropping systems and that may be economically mass produced. | Evaluate the fate of natural enemy life stages under field conditions to identify the appropriate developmental stage to be released. | Develop necessary technology for release of the appropriate natural enemy life stage. | Evaluate release technology effects on natural enemy life history characteristics, behavior, and ability to suppress whitefly populations. | Facilitate transfer of mass-rearing technology to commercial interests as necessary. |
| • **Evaluate augmentative parasitoid, predator, or pathogen releases.** | Initiate studies on natural enemy augmentation with identified high potential natural enemies. | Conduct releases on selected crop systems at various rates of release. | Identify optimal release strategies for key cropping systems. | Continue evaluation of releases, determine need for additional releases. Compare results in different cropping systems and environments. | Analyze information and make recommendation regarding need for expansion of the approach. |
| • **Evaluate the ability of exotic natural enemies to suppress whitefly populations under field conditions.** | Identify sites suitable for the release and subsequent evaluation of each candidate natural enemy. Conduct inoculative releases of natural enemies. | Evaluate establishment of exotic natural enemies within target release area. Determine if additional releases are necessary. | Assess spread of established natural enemies and their ability to suppress whitefly populations. | Continue to assess the spread of established natural enemies and their ability to suppress whitefly populations. Evaluate program progress and determine if additional strategies are necessary. | Complete program analysis. Publish program assessment and conduct an economic assessment. |

**Table D. Natural Enemy Ecology and Biological Control (continued)**

| Approaches/Goals[a] | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| **Systematics, ecology, and population dynamics of natural enemies[b]:** | | | | | |
| • **Clarify systematics of predators, parasitoids and pathogens.** | Conduct taxonomic studies of species within targeted release sites. Verify taxonomic purity of mass-reared natural enemies. Complete taxonomic work on poorly characterized but important groups. Assist in determining most suitable natural enemies for release through biogeographical analysis | Provide taxonomic support for importation and mass-rearing programs. Publish keys to assist in species identifications. | Provide taxonomic support for importation and mass-rearing programs. | Provide taxonomic support for importation and mass-rearing programs. | Provide taxonomic support for importation and mass-rearing programs. |
| • **Determine *Bemisia* - natural enemy-host plant (Tritrophic) interactions.** | Initiate studies to identify mechanisms involved in *Bemisia* - and natural enemy plant attraction. | Study plant characteristics mediating whitefly population densities. | Study compatibility of characteristics of plant traits mediating whitefly populations with the abilities of natural enemies to suppress whitefly populations. | Assess the implementability of favorable tritrophic interactions within the context of an whitefly management program. | Implement and evaluate large scale crop management programs for suppression of whitefly populations. |
| • **Identify the attributes of natural enemy biology and population level interactions to explain biological control successes and failures.** | Assess the value of the *Bemisia* biological control research to evaluate key issues to the science of biological control. | In conjunction with field evaluations, validate predictions made by behavioral and population models important to biological control. | Assess deviations between theoretical predictions and field data. | Evaluate behavioral or population level parameters that may explain observed deviations. | Quantify the impact of basic research on the development of feasible biological control programs for *Bemisia* and the advancement of the field as a science. |

[a] See Table C for complementary research.
[b] See Table A for complementary research.

**Table E. Host Plant Resistance, Physiological Disorders, and Host Plant Interactions**

| Approaches/Goals | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| **Characterize resistance mechanisms and identify chemical/morphological components, and study effects of insect adaptation.** | Identify potential sources of germplasm for disease, plant disorders and whitefly resistance.[a] | Determine physiological and/or morphological basis for resistance, & effects of host-plant history and insect adaptation on plant resistance to whiteflies. Continue to identify resistant germplasm. | Elucidate biochemical and molecular basis for resistance. Continue to identify resistant germplasm. | Determine potential for transfer of resistance traits. | Evaluate potential for incorporating *Bemisia*, plant disorder and disease resistance into acceptable plant type. |
| **Develop molecular level techniques to produce resistant germplasm.** | Identify physiological processes of whiteflies to target for inhibition. | Identify natural products for inhibiting processes. | Isolate the relevant biosynthetic enzymes that encode for natural products inhibiting processes. | Insert genes into plants via plant transformation.[b] | Evaluate potential of newly transformed germplasm. |
| **Incorporate resistance traits into commercial genotypes.** | Identify and isolate genetic sources of resistance for transformation and/or breeding. | Insert genes into plants[b] via plant transformation. | Evaluate potential of newly transformed germplasm. | Continue to refine resistance factors to improve resistance in newly transformed germplasm. | Incorporate other desirable plant characteristics for crop production. |
| **Determine influence of host plant morphology, physiology and phenology on feeding behavior and competition.[c]** | Characterize nutritional and other preference properties of various host plants. | Determine the biochemical mechanism regulating adaptation to host plants. | Determine changes in whitefly gene expression in response to host manipulation. | Relate changes in gene expression to whitefly physiology. | Summarize and disseminate results. |
| **Define whitefly feeding and oviposition behavior and investigate approaches for interrupting whitefly feeding and digestion.[d]** | Investigate approaches for interruption of feeding, assimilation, development and reproduction. | Identify physiological and morphological mechanisms regulating processes. | Determine biochemical and molecular basis for inhibiting processes. | Determine potential for transfer of resistance traits. | Insert genes into plants[a] via plant transformation. |
| **Study whitefly toxicogenic plant reactions.** | Determine effects of whitefly feeding on host plant physiology, morphology and anatomy. | Determine biochemical basis for physiological response of plant. | Elucidate changes in plant gene expression. | Identify resistance germplasm. | Evaluate potential for transferring new germplasm. |

[a] See Table B for additional plant disease resistance research.
[b] Progress at this point may extend to several year research.
[c] See Section A.
[d] See Section A, approach #9.

**Table F. Integrated and Areawide Pest Management Approaches and Crop Management Systems**

| Approaches/Goals[a] | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| **Development:** | | | | | |
| **Study whitefly-crop interactions[b] as cultural components that affect population dynamics, e.g., water, nutrients, plant population, planting/ termination/harvest dates, other farm practices, intercrop relationships.** | Identify potential beneficial or exacerbating farm practices or inputs for testing. | Determine nature and character of relationship between interaction and whitefly population dynamics. | Identify mechanisms governing relationship and alter or manipulate factors that suppress whitefly dynamics. | Refine system, add other compatible components, evaluate economic impact; conduct field testing and evaluations. | Conduct economic analyses and determine next level of IPM/ICM systems evaluation. Develop recommendations of best management practices. |
| **Develop behavioral barriers[b] to whitefly colonization and population development, e.g., mulches, trap crops, intercropping, row covers, etc.** | Review potential behavioral disrupters and evaluate as potential IPM components. | Conduct field-level trials; quantify impact to crop and whitefly dynamics | Apply promising technologies to high-value crop systems; field test and evaluate. | Refine system, add other components, and conduct economic feasibility analyses. | Summarize and evaluate results; prepare crop systems-specific recommendations. |
| **Integration:** | | | | | |
| **Develop Integrated Pest Management[c] systems using dual or multiple control tactics, e.g., cultural, biological, chemical, host plant resistance, etc.** | Identify candidate dual or multiple control tactic systems, e.g., IGRs and natural enemy conservation. | Initiate field testing of candidate systems. | Continue field testing & evaluate feasibility of large scale testing; add components as necessary. | Initiate large-scale experiments; incorporate economic evaluation. | Evaluate multiple component system as potential deliverable; prepare recommendations. |
| **Integrate sampling with other key components of IPM systems, e.g., thresholds, economics, decision-making, biological control, etc.** | Develop or modify sampling systems for new crops; integrate with thresholds and decision-making. | Establish practical utility of system through economic analyses; field efficiencies and costs. | Integrate additional control components into sampling, threshold & decision-making systems | Evaluate in whole field systems. Identify weaknesses; target improvements. | Evaluate redesigned decision systems; continue field testing and economic analyses. |
| **Delivery and Implementation:** | | | | | |
| **Elevate single field/farm practices to areawide community-based contexts; develop methodology for installing and evaluating areawide control technologies and their impact.** | Identify agricultural communities amenable to areawide management; conduct thorough pre-implementation evaluation. | Install control technologies into community; develop systems for evaluation. | Identify additional IPM/ICM compatible components. Re-assess and adapt program. Conduct areawide economic analyses. | Formulate clientele surveys; develop & begin to implement protocols for evaluating areawide technologies. | Refine, reevaluate and identify weaknesses. Formulate recommendations for future areawide management systems. Conduct surveys. |

**Table F. Integrated and Areawide Pest Management Approaches and Crop Management Systems**

| Approaches/Goals[a] | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| **Implement and deliver Integrated Pest Management and Integrated Crop Management systems or system components to clientele.** | Develop and distribute provisional IPM & ICM recommendations. | Conduct whole farm/operation demonstrations of IPM systems. | Expand sites of testing with grower cooperators; conduct validation studies. | Incorporate new information and economics into recommendations. | Validate new components; finalize recommendations; expand to new crops. |

[a] See Tables A to E for additional complementary research.
[b] See Table A for additional complementary research.
[c] See Table E for additional complementary research.